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POLLUTED GROUNDWATER:
ESTIMATING THE EFFECTS OF MAN'S ACTIVITIES

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Presents a method for estimating kinds, amounts, and trends of groundwater pollution caused by man's activities. Describes preliminary research for a number of examples: unlined earthen basins and lagoons used by the pulp and paper industry, petroleum refining, and primary metals industries; phosphate mining wastewater ponds; agricultural fertilizer use; and beef cattle feedlots. Relies primarily on census data, other statistical data, and descriptions of production processes used. Estimates past and projected volumes and areas covered by potential pollutants so that geohydrological analysis can be used to estimate the infiltration potential of pollutants. Results are not definitive but intend only to illustrate use of the methodology for geographical areas of interest. (W. E. Rogers — TEMPO)

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POLLUTED GROUNDWATER: ESTIMATING THE EFFECTS OF MAN'S ACTIVITIES

by

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ABSTRACT

Data on the quality of the nation's groundwater are sparse and are expensive to obtain through conventional sampling of water from wells. A supplementary approach to monitoring is to estimate kinds, amounts, and trends of groundwater pollution by relating them to man's activities.

Preliminary research on methodology for estimating the polluting effects on groundwater of man's activities has been carried out for a number of examples: unlined sedimentation basins and lagoons used by the pulp and paper industry, petroleum refining, and primary metals industries; wastewater ponds in phosphate mining; agricultural use of chemical fertilizers; and beef cattle feedlot operations. The methodology relies primarily on readily available census and other statistical data, together with descriptions of the processes used in the activities examined. Estimates are made of past and projected volumes and areas covered by potential pollutants. Geohydrological analysis is then applied to estimate the extent to which these potential pollutants may enter the groundwater.

The results of the broad preliminary analyses are not definitive, but are intended only to illustrate the applicability of the methodology to whatever geographical areas are of interest.

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CONCLUSIONS

(1) Estimating actual and potential groundwater pollution by analyzing man's activities is not only feasible, but appears to be a valuable supplement or even an alternative to the conventional approach of depending upon samples from water wells to monitor groundwater pollution. Trends in groundwater pollution may be more easily deduced, and future pollution predicted with greater confidence, by analysis of man's activities than by extrapolating data from water-well sampling.

(2) The methodology described is readily applicable to all geographical areas for which the necessary data are available. The reliability of estimates of groundwater pollution increases when small areas are analyzed, because of geological homogeneity and greater precision of data. However, as demonstrated in this study, the approach can provide a quick and useful synoptic estimate of the geographic incidence of pollution from a particular activity; the relation of pollution to population distribution or to aquifers can be thus examined.

(3) The analysis of man's activities should be carried out only to the precision justified by hydrogeologic knowledge of the area in question (eg, if infiltration rates must be estimated, they can vary by an order of magnitude; if such uncertainties exist, they make the results of the analyses relatively insensitive to the assumptions concerning man's activities and processes).

(4) The coincidence of various pollution sources and the potential for polluting groundwater in a given geographic area can be surveyed rapidly to assess the potential buildup of pollution from a number of activities.

(5) For a particular activity, the approach can be used to assess the relative importance of various processes that may pollute groundwater. For example, the volumes of effluent treated by the pulp and paper industry in unlined sedimentation basins and in lagoons are of the same order of magnitude but, because of differences in the processes, the potential for groundwater pollution from unlined sedimentation basins is minuscule compared to that from lagoons.

(6) Proposed regulations or controls on pollution may be evaluated by analyzing the effect of different processes with respect to groundwater pollution. Such analyses may help to evaluate the effects of imposing "best practicable" and "best available" treatment processes on various time scales, perhaps for comparison to socioeconomic costs associated with different regulations.

SUMMARY

On the basis that information describing groundwater pollution is sparse, research was undertaken to investigate the feasibility of "monitoring" groundwater quality by analyzing man's activities which may pollute groundwater. This approach to monitoring may appear to be less direct than the conventional practice of taking samples from wells and performing biochemical analyses. However, samples from a well represent water quality only in the immediate vicinity of the well, and may fail to reveal the existence of severe pollution only a few tens or hundreds of feet away in the aquifer. Therefore, the methodology described here may be more complete and no less direct than that of water-well sampling.

The results of this brief study do not provide a picture of the quality of the nation's groundwater; it is to be emphasized that this was not the objective of the study. The results of the study are neither comprehensive nor conclusive. Rather, the study demonstrated the feasibility of the approach through actually searching out data and applying them methodically to selected examples of man's activities that may cause groundwater pollution. If the methodology is to be applied to other sources and kinds of pollutants to formulate specific descriptions of the probable present and future state of groundwater pollution, the need for further refinement and extension of the work is clear

Six exemplar industrial and agricultural activities were chosen for methodology development and analysis of potential impact on groundwater quality:

1. Pulp and paper manufacturing
2. Petroleum refining
3. Primary metals (steel) manufacturing
4. Phosphate mining
5. Agricultural fertilizer consumption
6. Beef cattle feedlots.

The first three of these activities are heavy users of water, accounting for about half of the total industrial water use in the United States (excluding hydroelectric power plants). The water is used both for cooling and for manufacturing subprocesses, with the subprocesses resulting in contamination requiring treatment before the wastewater can be released as surface runoff. Ironically, the increasingly stringent requirements for treatment of this wastewater before release into surface streams has resulted in a serious threat to groundwater quality since much of this treatment takes place in unlined basins for sedimentation and lagoons for biological treatment.

Phosphate mining also uses large amounts of water which becomes contaminated in the mining process. Current practice is to contain the waterborne mining byproducts ("slime") in open, unlined earthen pits for sedimentation.

Fertilizers applied to farmlands pose a threat to groundwater if they leach through the soil into underlying aquifers. Wastes from beef cattle feedlots may stand in holding basins or run off into surface streams, from which they may infiltrate downward into aquifers.

WASTEWATER FROM PAPER, PETROLEUM, AND STEEL INDUSTRIES

Assessment of the groundwater pollution potential arising from pulp and paper manufacturing, petroleum refining, and steel manufacturing was carried out on the basis of water used by these industries in each of 18 Industrial Water Use Regions as defined by the U.S. Bureau of the

Census, using 1964 and 1968 Census of Manufactures data as a baseline and projecting back in time to 1954 and ahead to 1983. The regional data for 1964 and 1968 included not only total water discharged, but wastewater given primary treatment (settling out of solids only) in unlined sedimentation basins and wastewater given secondary treatment (reduction of biological oxygen demand) in lagoons.

Regional data were not available for these industries for 1954 and 1959, but only national totals. Neither were data available on type of wastewater treatment, but only in total amount treated. Thus, it was assumed for the analysis that regional use distribution in previous years was approximately the same as that for 1964, and assumptions were also made regarding the relative amount of primary and secondary treatment to take into account increasingly stringent treatment requirements and increased treatment sophistication over the 1954-1968 period.

The 1969-1983 total water usage and primary and secondary wastewater treatment rates for these three industries were derived from industry growth rate projections by the University of Maryland's Bureau of Business and Economic Research, the expected impact of FWPCA and EPA pollution control requirements, and anticipated improvements in treatment technology.

Based upon average residence times for primary (separation of suspended solids) and secondary (biologic stabilization) treatment of wastewater and average depths of basins and lagoons, the volumes and acreages required for primary treatment basins and secondary treatment lagoons were calculated for each industry. This, coupled with the seepage rate of the basins and lagoons, which was estimated to average 30 inches per year, or about 2.5 acre-feet per acre of basin and lagoon, yields a rough idea of their potential for contaminating underlying aquifers. (In specific situations, the actual seepage rates may vary by at least an order of magnitude from the average that was used.)

SUMMARY

The pollution potential of primary treatment in unlined sedimentation basins appears to be minuscule compared with that of secondary treatment in lagoons for all three industries. The chief reason is that primary treatment in unlined basins is much less prevalent than is secondary treatment in lagoons, and treatment times required for lagooning are much greater than those for sedimentation. Sedimentation treatment of wastewater can ordinarily be completed in less than one working day; thus, only sufficient capacity for one day's output of treatable wastewater is required. In contrast, secondary treatment may require capacities of up to a month's wastewater output in order to complete treatment, and the lagoons must be much shallower than sedimentation basins in order to allow sufficient aeration for the reduction of biological oxygen demand (BOD) before the wastewater is released. It follows that secondary treatment of a given amount of wastewater may require up to 60 times more area than does primary treatment. The amount of seepage, of course, is directly proportional to the area covered.

Detailed descriptions of the methodology followed for pulp and paper, petroleum refining, and steel manufacturing wastewaters are given in Sections 2, 3, and 4, as are descriptions of their constituent pollutants. Some summary results follow.

Pulp and Paper Industry

Of the three wastewater cases examined, the pulp and paper industry was projected to have the largest volume of wastewater requiring secondary lagoon treatment through 1983 (see Figure i). From 1954 through 1968 and as projected through 1973, the curves of national figures for volume of water treated and the lagoon acreage required are congruent. Thereafter, increased volumes of wastewater per acre of lagoon have been projected due to anticipated adoption of technological improvements in secondary treatment. These improvements may take the form

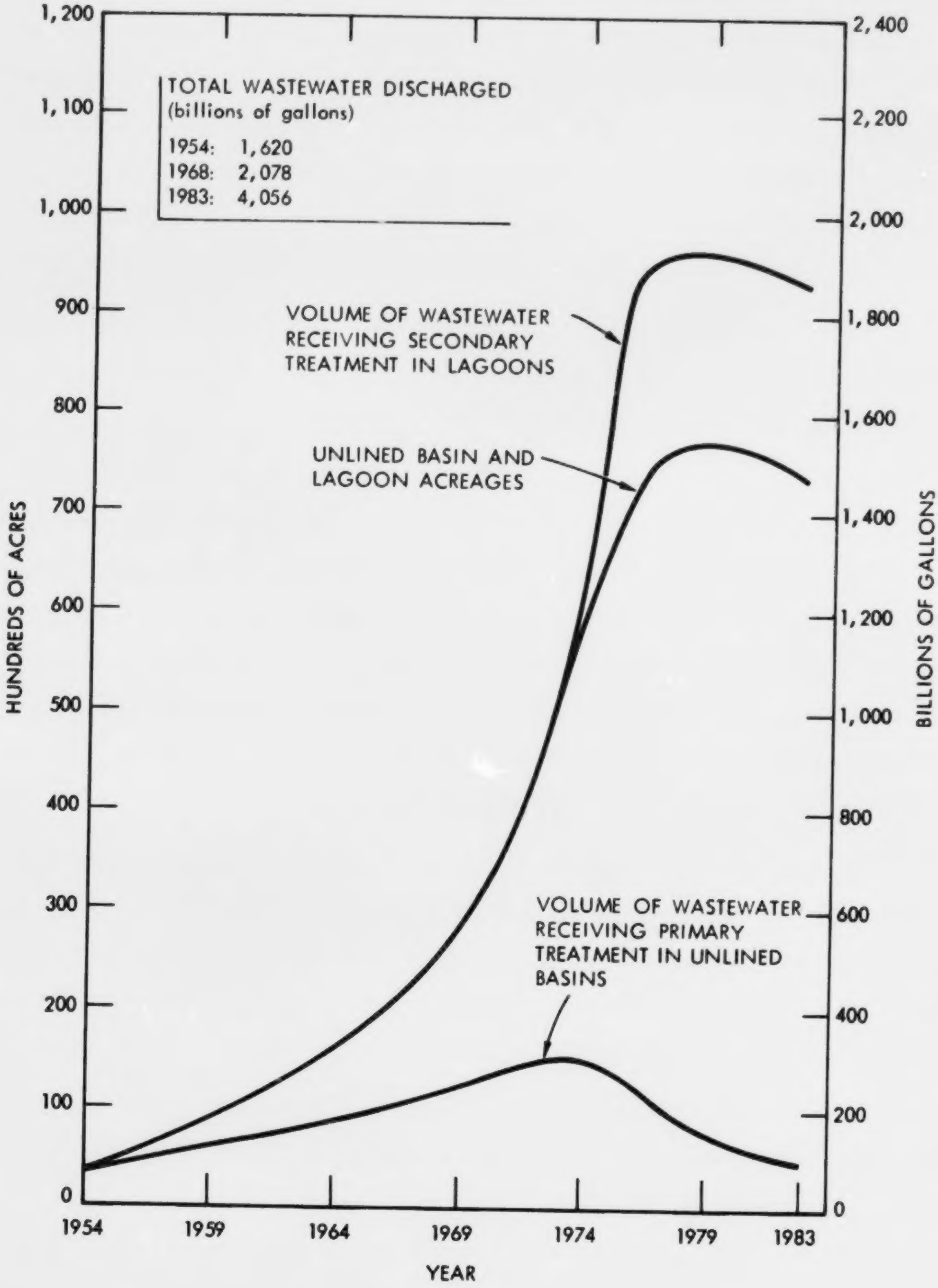

Figure i. Total U.S. pulp and paper industry wastewater treatment volumes and acreage covered, 1954-1983.

of lagoon aeration, allowing greater depth and shorter wastewater detention times, lining of lagoons to prevent seepage, or substitution of a different process for lagoon treatment in order to meet EPA requirements. Despite anticipated industry growth of more than 2 percent per year during the latter part of the projection period, both wastewater lagooned and lagoon acreage show a decline beginning in the late 1970s.

The major potential groundwater contaminants in the pulp and paper effluent are lignins, wood sugars, sulfates, sulfites, calcium compounds, grease, and color.

Based on treatment figures for 1954–1968, primary sedimentation treatment in unlined basins was projected to increase through 1973, but thereafter to decline because of the adoption of more advanced sedimentation processes to satisfy EPA water treatment regulations. The acreage of unlined sedimentation basins is not shown separately in Figure i because of the relatively insignificant area they occupy– 50 acres in 1954, rising to a projected peak of 190 acres in 1973, and declining to 60 acres in 1983.

Census data and regional projections for this industry show the Southeast, Pacific Northwest, and New England regions to have the greatest groundwater pollution potential from primary and secondary wastewater treatment. Their treatment volumes, areal coverage, and fractions of the national total are given in Table i.

Based on the seepage rate assumed for this study of 30 inches per year for unlined sedimentation basins and lagoons, the Southeast region would have subsurface infiltration of 34,000 acre-feet in 1968 and 75,000 acre-feet in 1983, or about 40 to 50 percent of the national total. In terms of regional density of treatment acreage, however, the New England region exceeds the Southeast region for the later years of the projection: it has one-fourth as much treatment acreage, but considerably less than one-fourth as much geographic area.

Table i. Pulp and paper industry primary and secondary wastewater treatment, 1954-1983.

Region	1954	1964	1968	1973	1977	1983
Southeast						
Billions of gallons and fraction of national total (%)	114(67)	296(62)	429(63)	693(51)	751(36)	647(37)
Hundreds of acres and fraction of national total (%)	23(51)	87(54)	136(56)	245(38)	333(44)	300(41)
Pacific Northwest						
Billions of gallons and fraction of national total (%)	13(8)	52(11)	66(10)	187(14)	363(17)	334(19)
Hundreds of acres and fraction of national total (%)	4(9)	13(8)	17(7)	63(9)	95(13)	93(13)
New England						
Billions of gallons and fraction of national total (%)	<1(.6)	2(.4)	2(.3)	66(5)	248(12)	244(14)
Hundreds of acres and fraction of national total (%)	0.3(.6)	1(.6)	1(.4)	34(5)	76(10)	75(10)
United States						
Billions of gallons	170	481	678	1,347	2,075	1,763
Hundreds of acres	45	160	241	726	753	731

Petroleum Refining Industry

The main petroleum refinery wastewater constituents of consequence to groundwater quality are oil, ammonia, suspended solids, phenols, spent caustics, and sulfides. Overall, this industry uses a volume of water in its processes comparable to that used by the pulp and paper industry. However, approximately 25 percent of the industry's water intake is solely for cooling purposes, of which increasing amounts are being recirculated: from 1954 to 1964 production output increased approximately 48 percent, while water intake increased by 13 percent.

Figure ii shows national petroleum refining industry wastewater treatment volumes and acreages of lagoons for 1954-1968 as obtained from census data. The values shown for 1968-1983 are projections based on a 2 percent per year growth rate of wastewater discharged. As projected, the volume and acreage of wastewater lagooned peaks in 1977, the year when industry must meet the EPA's requirement for use of the "best practicable technology" for wastewater treatment. The decline in treatment by lagooning beyond 1977 is based on the assumption that the petroleum refining industry will have begun by then to adopt alternative methods for secondary wastewater treatment in order to meet the more stringent EPA 1983 requirement for use of the "best available technology."

Unlike the pulp and paper and steel wastewater projection, the ratio of lagoon acreage to treatment volume remains constant for the petroleum refining wastewater projection. This is because no credit was given for expected technological advances in lagooning as it was in the other two industries.

Figure ii shows a decline in primary sedimentation treatment in unlined basins from 1964-1983. The decline reflects increased usage of other, more technologically advanced means of treatment, such as mechanical separators. The area covered by unlined sedimentation basins is not shown in the figure as it is so small as to be insignificant if plotted (about 2 percent of the lagoon acreage in 1964 and about 0.3 percent in 1983).

The largest past and projected processors of petroleum refinery wastewater are the Delaware and Hudson, Western Great Lakes, and

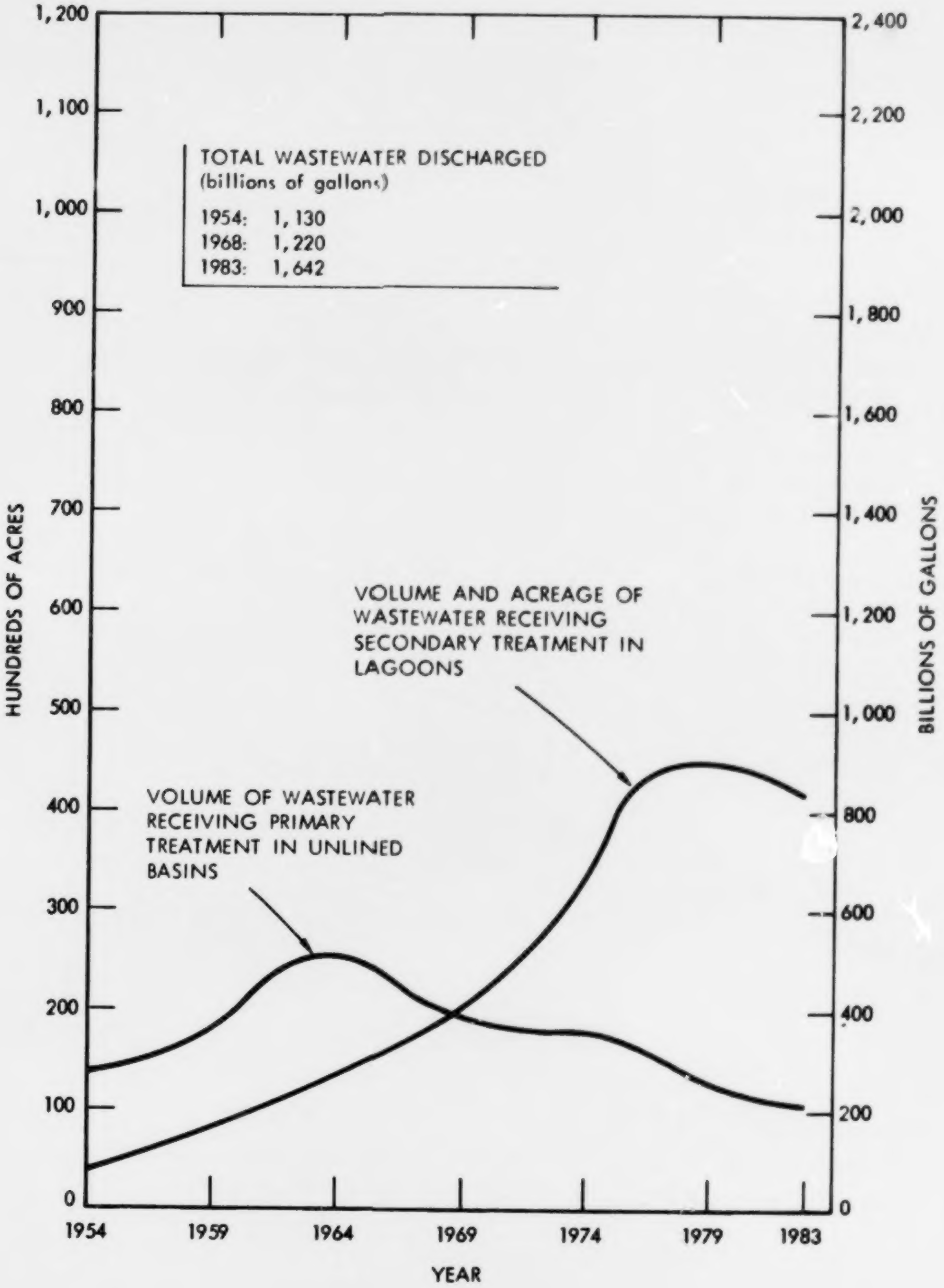

Figure ii. Total U.S. petroleum refining industry wastewater treatment volumes and acreage covered, 1954-1983.

Western Gulf regions. Their treatment volumes, area coverage, and fractions of the national total are given in Table ii.

Table ii. Petroleum refining industry primary and secondary wastewater treatment, 1954-1983.

Region	1954	1964	1968	1973	1977	1983
Delaware & Hudson						
Billions of gallons and fraction of national total (%)	96(26)	200(26)	198(28)	251(27)	290(25)	269(26)
Hundreds of acres and fraction of national total (%)	14(30)	40(28)	48(27)	77(25)	109(24)	110(26)
Western Great Lakes						
Billions of gallons and fraction of national total (%)	31(8)	65(9)	44(6)	89(10)	130(11)	120(12)
Hundreds of acres and fraction of national total (%)	2(4)	13(9)	8(5)	27(9)	48(11)	49(12)
Western Gulf						
Billions of gallons and fraction of national total (%)	112(30)	242(32)	239(34)	292(31)	328(28)	285(28)
Hundreds of acres and fraction of national total (%)	14(30)	47(33)	77(44)	91(30)	123(27)	115(27)
United States						
Billions of gallons	368	762	705	929	1,174	1,023
Hundreds of acres	47	144	176	305	448	420

The two largest processors, the Western Gulf and the Delaware and Hudson regions, are projected to process nearly identical amounts of wastewater by 1983. The fourth largest region, the California region, not shown in Table ii, is projected to process nearly as much wastewater by 1983 (98 billion gallons) as the third largest, the Western Great Lakes region.

The Western Gulf and Delaware and Hudson regions treat the largest volumes of wastewater throughout the 1954-1983 period. The Western Gulf in 1954 accounted for 30 percent of the national volume of petroleum refinery wastewater treated in unlined sedimentation basins and the Delaware and Hudson 24 percent, and these regions show fractions of 30 and 26 percent, respectively, for 1983. Total volume treated by unlined sedimentation peaks at 115 billion gallons in 1973 for the Western Gulf region and at 102 billion gallons in 1973 for the Delaware and Hudson region. The respective fractions of water lagooned in 1983 are about 27 percent and 26 percent of the national total for these two regions, with the Western Gulf region ranging from 29 billion gallons in 1954 to 225 billion gallons in 1983. The 29-year total for the Western Gulf region amounts to more than 4,000 billion gallons with the Delaware and Hudson region only slightly less.

Although the regional figures do not show concentrations of unlined basins and lagoons, it is perhaps noteworthy that the Delaware and Hudson region, which lagoons a quarter of the nation's petroleum refining industry wastewater, is also one of the smallest industrial water use regions in the country. At the projected rate of growth in lagooning, during the 1977 period this region will contain 10,800 acres – about 17 square miles – of lagoons. Based on the lagoon seepage rate of 30 inches per year assumed in this study, the potential exists for 27,000 acre-feet per year of polluted water to seep underground in this region alone.

At the projected nationwide rates of industry growth and the assumed seepage rate for lagoons, by 1977 more than 111,000 acre-feet per year of effluent might seep into the ground. It must be emphasized, however, that the projections cited here are not forecasts, but serve only to demonstrate a methodology for the estimation of potential groundwater impacts.

Primary Metals Industries Wastewater

About 25 to 30 percent of the water used by the primary metals industries requires treatment for removal of pollutants, with the rest being used only for cooling purposes. In 1968, for example, only 1,430 billion gallons of wastewater underwent primary and/or secondary treatment although 4,692 billion gallons were discharged.

The major pollutants from this industry that potentially affect groundwater quality are suspended and dissolved solids, iron, ammonia, cyanide, phenol, oil, and the heavy metals—arsenic, cadmium, chromium, lead, and zinc. The latter are especially hazardous to human health.

Figure iii summarizes volumes of wastewater treatment in the primary metals industry from 1954 to 1968 as determined from census data and projected treatment from 1969 to 1983 based on assumptions and estimates of industry growth and treatment practices, technological change, and compliance with Federal treatment regulations.

As with the pulp and paper and petroleum refining industries, primary metals industry wastewater sedimentation treatment in unlined basins and biological treatment in lagoons is expected to peak in the late 1970s to meet the initial EPA treatment requirements, and then decline subsequently as more technologically advanced alternative treatment methods are adopted.

The lagoon acreage projections of Figure iii reflect a 50 percent excess capacity over volume of wastewater treated through 1975, when the ratio begins to change. This is accounted for by adoption of expected technological improvements in lagooning which will allow deeper lagoons and shorter wastewater detention periods, thereby decreasing acreage requirements for treatment of a given volume of wastewater.

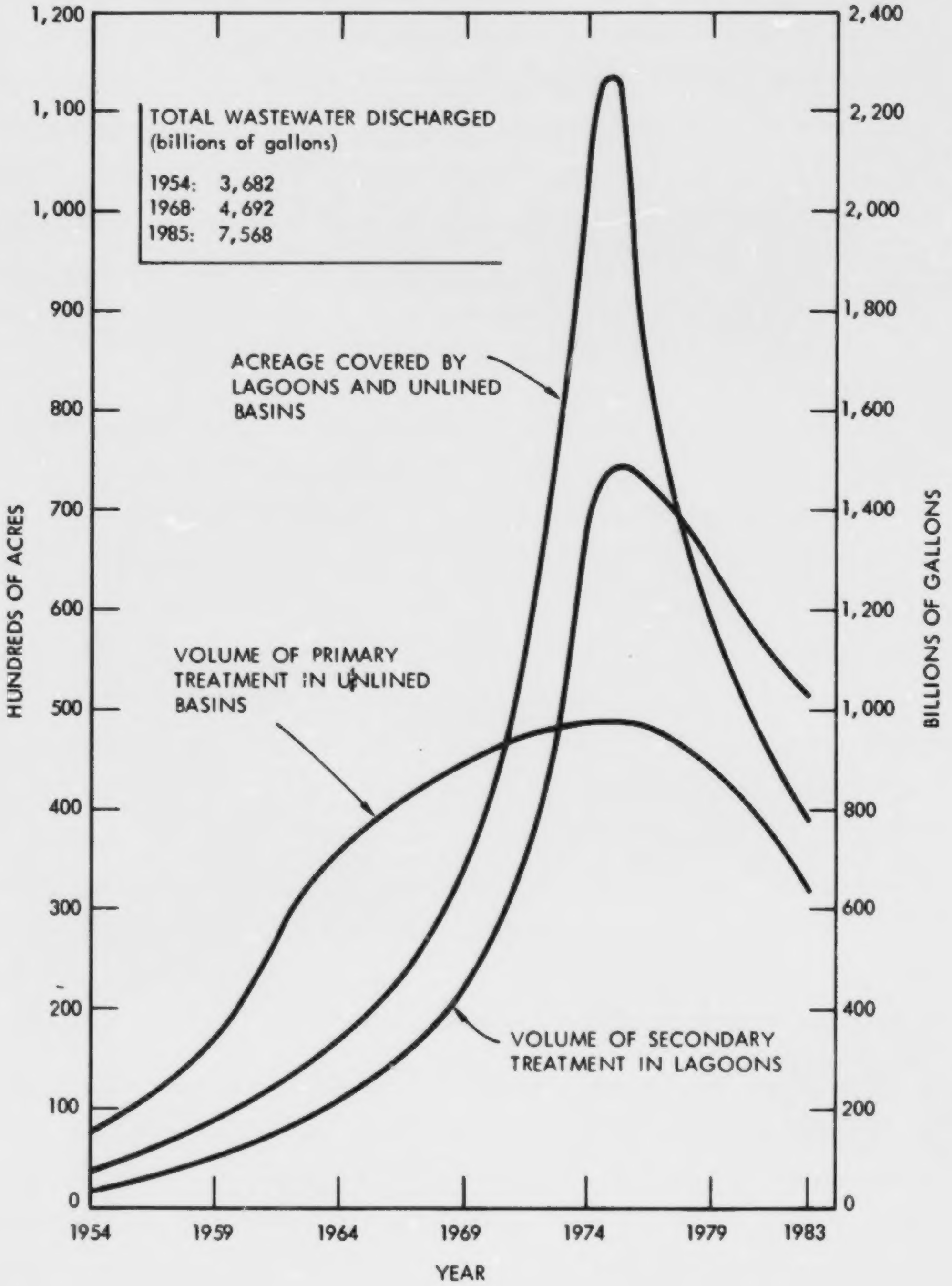

Figure iii. Total U.S. primary metals industries wastewater treatment volumes and acreage covered, 1954-1983.

Primary metals production—about 90 percent of which is steel—is concentrated around the Great Lakes and on the Eastern Seaboard. The regions with the greatest volumes and acreage of wastewater undergoing unlined sedimentation and lagooning are the Eastern Great Lakes, Ohio River, and the Western Great Lakes. These three areas, listed in Table iii, have treated, and are projected to continue to treat, the largest volumes of wastewater and to have the greatest acreage in use for wastewater treatment. Together they account for about 75 percent of the industry's wastewater treatment from 1954-1983.

The largest of the three regions in terms of wastewater receiving primary and/or secondary treatment is the Western Great Lakes region. This region is projected to incur a peak wasteload for unlined basin and lagoon treatment by 1977, processing 840 billion gallons of wastewater, in basins and lagoons covering 28,000 acres.* The next largest, the Ohio River region, also peaks in 1977 at 21,400 acres of basins and lagoons processing 640 billion gallons of wastewater in the same year. During the late 1970s, the fractions of the national total of primary metal industries unlined basins and lagoons for these three regions are: Western Great Lakes, 35 percent; Ohio River, 27 percent; and Eastern Great Lakes, 16 percent. From 1954 to 1973, the Western Great Lakes region is projected to have a 33-fold increase in basin and lagoon acreage, from 900 acres to 29,400 acres. All the other primary metals industries regions exhibit substantial increases in acreage as well.

Assuming infiltration levels for unlined basins and lagoons of 30 inches per year, the Western Great Lakes region has in 1973 a groundwater pollution potential of about 75,000 acre-feet of wastewater seepage from its unlined basins and lagoons. In the same year, the Ohio River region has an infiltration potential of nearly 55,000 acre-feet of wastewater and the Eastern Great Lakes region 32,000 acre-feet.

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*Acreage of basins and lagoons, however, is greater (29,400 acres) in 1973. Expected technological improvements over the 1973-1977 period account for the difference.

Table iii. Primary metals industries primary and secondary wastewater treatment, 1954-1983.

Region	1954	1964	1968	1973	1977	1983
Eastern Great Lakes						
Billions of gallons and fraction of national total (%)	42(19)	191(20)	171(14)	306(15)	383(16)	259(16)
Hundreds of acres and fraction of national total (%)	6(17)	33(19)	35(13)	120(16)	128(16)	62(16)
Ohio River						
Billions of gallons and fraction of national total (%)	54(25)	181(19)	258(21)	513(26)	640(27)	434(26)
Hundreds of acres and fraction of national total (%)	6(17)	17(10)	41(15)	202(26)	214(27)	104(26)
Western Great Lakes						
Billions of gallons and fraction of national total (%)	63(29)	65(7)	440(36)	735(37)	840(35)	572(34)
Hundred of acres and fraction of national total (%)	9(25)	41(24)	89(32)	294(38)	280(35)	136(34)
United States						
Billions of gallons	220	938	1,203	1,980	2,409	1,663
Hundreds of acres	36	174	274	770	799	398

At the projected volumes and acreages of unlined basin and lagoon wastewater treatment, over the 29-year projection period the Western Great Lakes region, which covers about 2 percent of the continental United States land area, could absorb more than 1 million acre-feet of wastewater through subsurface infiltration. Given the assumed industry growth rates, treatment practices, industry distribution, and infiltration rates, over the 29-year projection period the three areas taken together are subject to wastewater subsurface infiltration of up to 2.25 million acre-feet with its attendant long-term groundwater pollution implications.

PHOSPHATE ROCK MINING INDUSTRY

The approach used for the phosphate mining industry departs from that employed for the other three wastewater-producing industries examined. The analysis is more specific because it is concerned with a single wastewater-treatment practice in a limited area and thus more detailed data were available. Slime ponds are the treatment process and the area is the western part of Polk County, Central Florida, where about 65 percent of the U.S. phosphate rock production originates.

Phosphate rock is mined by blasting the phosphate matrix with hydraulic guns to break it up. Through the use of more water the phosphate is separated from the clay, sand tailings, and other soil components. The waste products from the matrix, coupled with the water used to break it up and to separate the phosphate, form a waste slime which is settled in slime ponds. These are of two types – "active" and "inactive." Active ponds receive slimy wastewaters and desedimented water is extracted from them for reuse. The disposal of slime is the only function of the inactive ponds, which do not dry up, and the wastewater is simply allowed to remain in them, resulting in a buildup of sedimentation. The slime enters the ponds at a solids concentration of 4 to 5 percent and quickly settles to 10 to 15 percent. Further concentration, even after years of settling, never exceeds 25 to 35 percent solids. The suspended solids content of wastewater in slime ponds, as well as the mineralogic and chemical composition of these solids – primarily oxides of phosphorus, iron, aluminum, calcium, and magnesium – are groundwater pollutants.

The infiltration rate of slime wastewater ponds into underlying groundwater aquifers is assumed to be the same as that described for the other industries' sedimentation basins and lagoons: 30 inches per year.

The annual projected growth rate for the phosphate mining industry is estimated to be 5 percent (see Figure iv) with a commensurate yearly increase in slime production. On this basis, Polk County is presently subject to underground infiltration of 64,000 acre-feet of water per year from its slime ponds. At the projected rate of industry growth, the infiltration in Polk County alone could approximate 100,000 acre-feet per year by 1983. On a national basis, the infiltration may approach 150,000 acre-feet per year by 1983, with about 75 percent of this occurring in Polk County and other parts of Florida, assuming that the geographic distribution of industry production does not change greatly.

Details of the analytical approach and the data used in projecting phosphate rock mining production and its waste products are given in Section 5.

AGRICULTURAL FERTILIZER CONSUMPTION

The assessment of agricultural fertilizer consumption was based largely on U.S. Department of Agriculture statistics compiled for nine fertilizer-consuming regions in the Continental United States as defined by the U.S. Bureau of the Census, as well as on Bureau of the Census agricultural statistics.

Determining historical consumption of fertilizer by region was a relatively straightforward process; all historical data (1954-1970) were taken from USDA's Agricultural Statistics. The projected consumption for the years 1971 through 1985 employs the University of Maryland's Bureau of Business and Economic Research estimates of fertilizer growth rates and assumes that the 1970 regional proportions of consumption will remain stable through 1985.

Since the fertilizer-consuming regions vary greatly in size and amount of fertilized cropland acreage (as distinct from total harvested cropland acreage), it was necessary as part of the analysis to determine the past and future fertilized acreage in each region to derive trends in

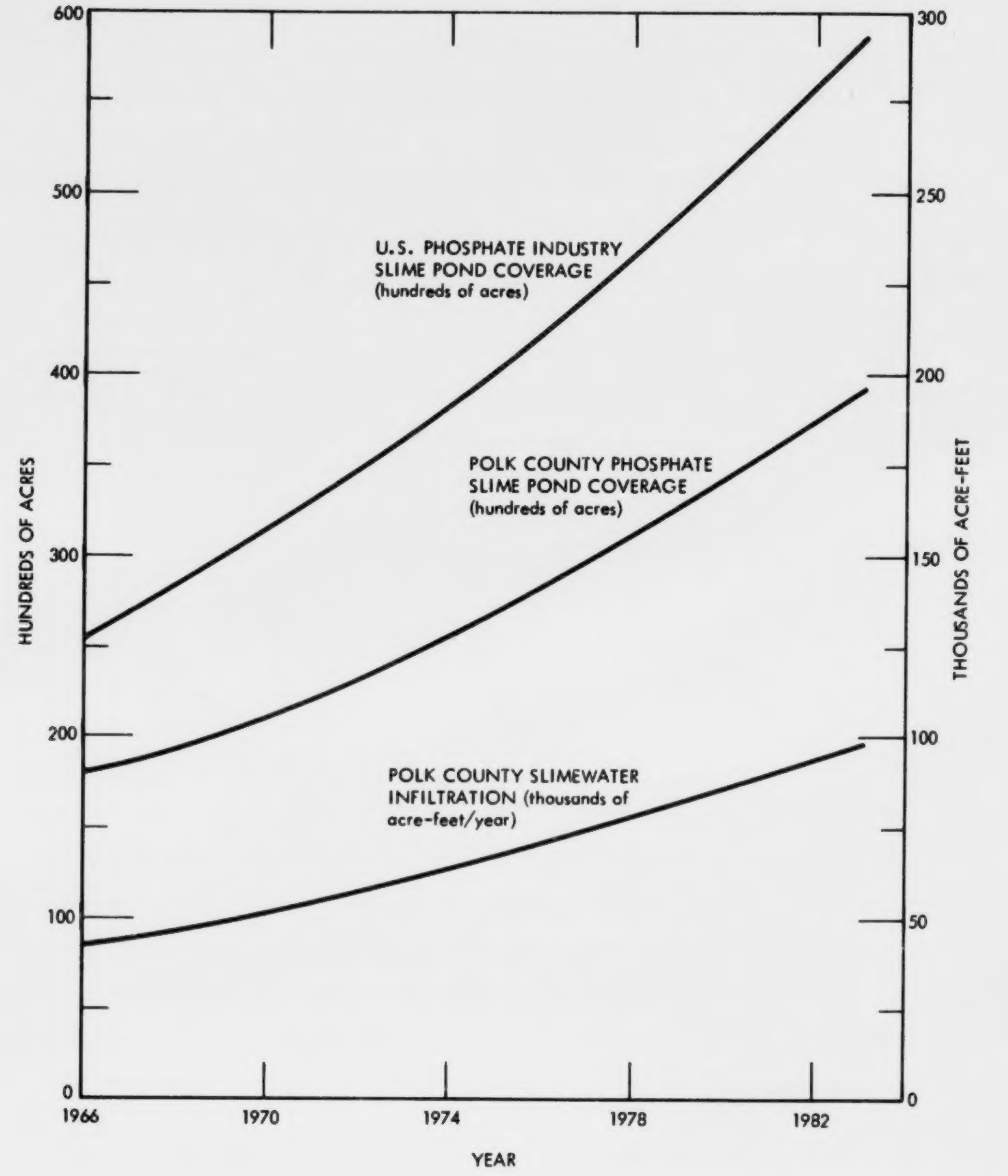


Figure iv. Polk County, Florida phosphate slime generation, 1966-1983.

amount of fertilizer application per acre. The regional figures for 1954-1964 fertilized acreage were taken directly from Bureau of Census statistics. Only the national figures were available for 1969 and 1970, so these were prorated among the regions by using the regional distribution percentages for 1964.

Data for 1971 and succeeding years were not available. Total harvested cropland acreage was projected at 5-year increments for 1975, 1980, and 1985. The projection assumed that essentially all of the acreage in idle cropland in 1964-1969 will be put to use as harvested cropland by 1975. This assumption was based on population growth coupled with policies aimed at increasing food output.

The ratio of fertilized to unfertilized harvested cropland acreage in the nine regions for 1969-1970 was used to estimate the acreage in each region that would be under fertilization for the years 1975-1985, based on the assumption that any cropland which would benefit from fertilization would already have been under fertilization by 1969-1970.

The analysis indicates that nationally, annual fertilizer consumption increased 1.8 times from 22 million tons in 1954 to 40 million tons in 1970. A similar margin of growth is expected between 1970 and 1985, when application of 74 million tons is anticipated. Since little increase is projected in fertilized harvested cropland acreage, this increase in consumption corresponds to an increase in application density per fertilized acre as shown in Figure v.

Figures for the regional amounts of fertilizer application per cropland acre were derived by dividing the past and projected regional tonnage of fertilizer consumption by the acreage treated. The three largest consumers of fertilizer, both historically and projected, are the South Atlantic, East North Central, and West North Central regions, whose consumption figures and per-acre application rates are given in Table iv. Together these regions account for about 60 percent of the

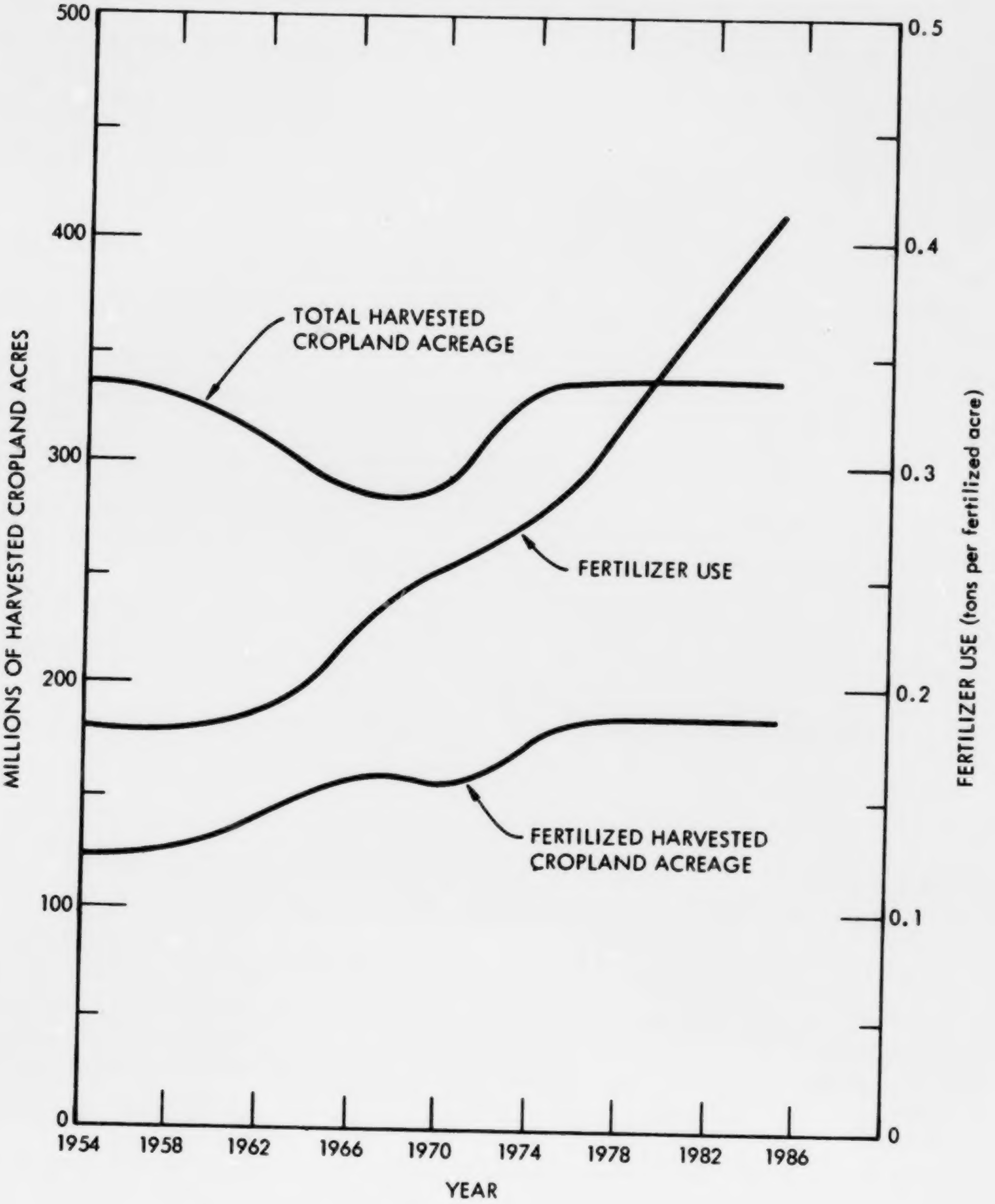


Figure v. Application of fertilizer in the United States to fertilized harvested croplands, 1954–1985.

Table iv. Agricultural fertilizer consumption, fertilized harvested acreage, and per-acre application rates for the three leading fertilizer consumption regions and the United States, 1954-1985.

Region	1954	1964	1970	1975	1980	1985
South Atlantic						
Millions of tons and fractions of national total (%)	6.58 (30)	7.23 (23)	7.78 (19)	9.97 (19)	12.07 (19)	14.19 (19)
Millions of fertilized acres	20.9	17.2	17.7	20.8	20.8	20.8
Tons applied per fertilized acre	0.31	0.42	0.45	0.48	0.58	0.68
East North Central						
Millions of tons and fraction of national total (%)	4.52 (20)	6.13 (20)	8.76 (21)	11.23 (21)	13.60 (21)	16.00 (22)
Millions of fertilized acres	31.0	33.0	33.4	39.9	39.9	39.9
Tons applied per fertilized acre	0.15	0.19	0.26	0.28	0.34	0.40
West North Central						
Millions of tons and fraction of national total (%)	2.18 (10)	4.85 (16)	9.12 (22)	11.69 (22)	14.15 (22)	16.63 (22)
Millions of fertilized acres	26.4	44.1	44.7	53.3	53.3	53.3
Tons applied per fertilized acre	0.08	0.11	0.20	0.22	0.27	0.31
United States						
Millions of tons	22.0	30.90	40.80	52.30	63.30	74.40
Millions of fertilized acres	123.0	133.0	153.0	182.5	182.5	182.5
Tons applied per fertilized acre	0.18	0.20	0.27	0.29	0.35	0.41

national consumption. Of these, the South Atlantic region is projected to have the heaviest application rate in 1985 with 0.68 tons per acre. Two other regions not shown in the table, the New England and California regions, have the next heaviest application rates with 0.57 tons per acre projected for 1985.

Details of the analytical approach, the data used, and regional consumption are given in Section 6. While data are available to compute consumption by type of fertilizer (principally commercial chemical mixtures and unmixed nitrogen, phosphorus, and potash), this level of analysis was not attempted in this demonstration of methodology, nor was any attempt made to relate density of application to groundwater pollution potential.

BEEF CATTLE FEEDLOT INDUSTRY

The methodological approach to assessing pollution from beef cattle feedlots was based on statistics compiled for eleven cattle feeding regions in the continental United States. The available statistics were compiled by USDA and EPA for yearly cattle feedlot production from 1962 through 1972. Growth rates for 1972-1983 feedlot beef production are those of the University of Maryland's Bureau of Business and Economic Research.

Of the constituents present in beef cattle wastes that are possible groundwater pollutants, nitrogen comprises 3.1 to 9.8 percent of total solids, potassium 1.7 to 3.8 percent, and phosphorus 0.3 to 1.7 percent, with other constituents occurring in lesser amounts. The mechanisms by which these constituents might pollute groundwater are direct infiltration of leachates through feedlots and by rainwater or flushing water from feedlots that may be caught and held or treated in ponds or lagoons.

Several estimates and assumptions were used to derive the amount and concentrations of beef cattle wastes from regional feedlot activities.

These deal with average weight per head, average daily amount of waste produced per head, average length of feedlot residence, average feedlot area per head, seasonality of feedlot production, and regional distribution of beef cattle production in the United States.

Historical data concerning average weight per head upon entering and leaving feedlots were assumed to remain unchanged for the projection period of 1971-1983. The amount of waste per head per day was derived as an average from several estimates. Average feedlot area per head estimates were available for only four regions, so a conservative estimate of 200 square feet per head was assumed for the remaining seven regions. Based on historical data, seasonality of feedlot population was assumed to be relatively stable, and regional distribution of production was assumed to remain unchanged for the 1971-1983 period.

Past data and beef production growth rate forecasts were used to prepare regional estimates of feedlot acreage and annual amount of waste deposits for 1962 through 1983. Figure vi indicates that by 1983 nationwide beef production, feedlot area, and animal waste deposits will be more than double the 1962 figures.

The largest producers of fed beef cattle over the 1962-1983 projection period are the Corn Belt, Northern Plains, and High Plains regions. These three regions are projected to account for about 70 percent of the nation's feedlot beef cattle production from 1971 to 1983, with concomitant shares of feedlot acreage and manure generation as shown in Table v. Two of these regions, the Corn Belt region and Northern Plains region, adjoin each other. Over the 1962-1983 period they are projected to accumulate more than 0.8 billion tons of cattle feedlot wastes, or about one-half the U.S. total, amounting to a regional concentration about six times that of the rest of the country.

Details of the study approach are presented in Section 7 along with a breakdown of the principal constituents of cattle excreta. Although

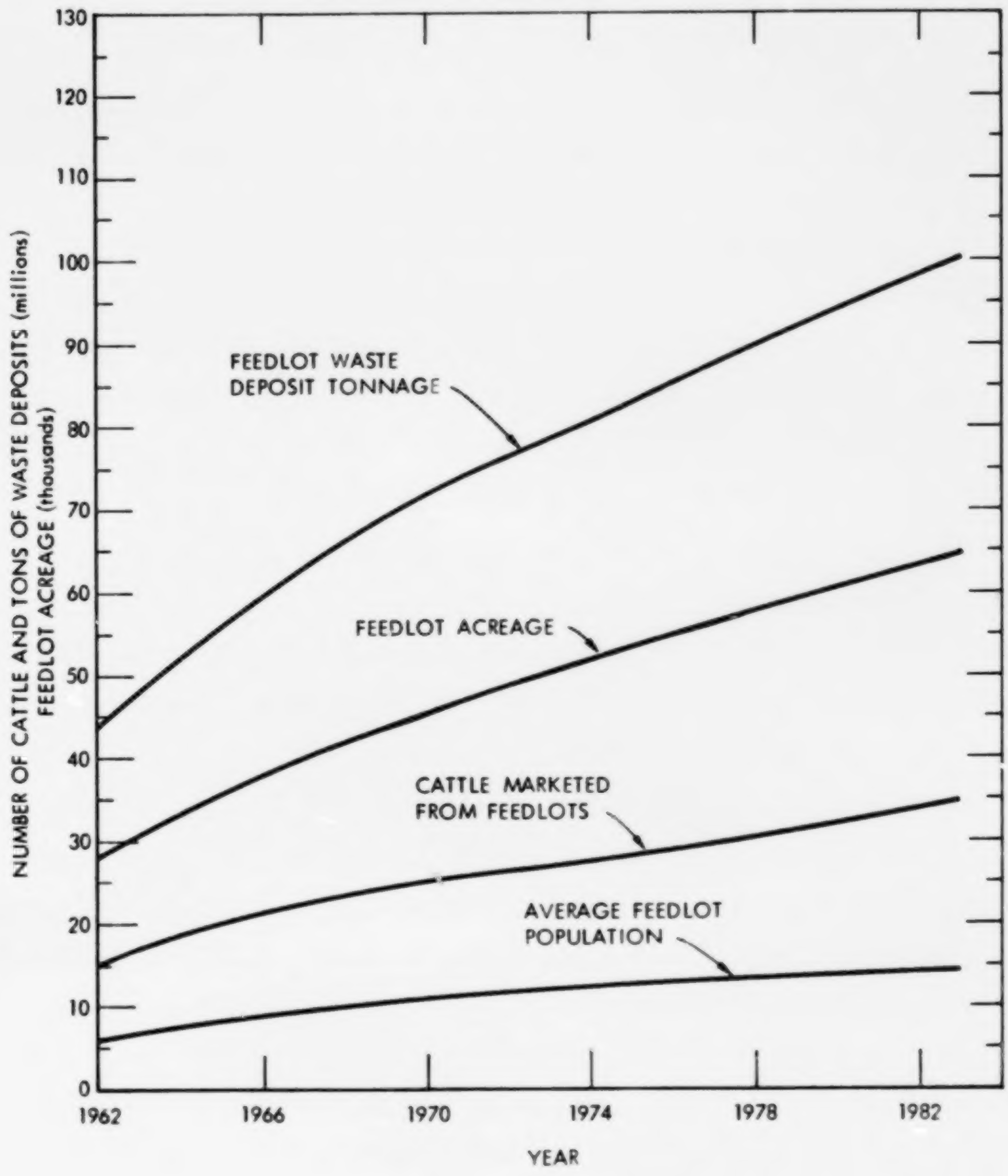


Figure vi. U.S. feedlot beef cattle marketed, average feedlot population, and waste deposit tonnage and acreage, 1962-1983.

sufficient data are available to disaggregate regional feedlot production into State production, this was not attempted in the present limited methodology demonstration, nor was any attempt made to assess the impact of feedlots on groundwater integrity.

Table v. Fed beef cattle production, feedlot acreage, and waste deposits of the three leading feedlot regions, 1962-1983.

Region	1962	1968	1971	1975	1979	1983
Corn Belt						
Millions of cattle marketed and fraction of national total (%)	5.23 (35)	7.28 (32)	6.64 (26)	7.42 (26)	8.23 (26)	9.04 (26)
Millions of tons of waste deposits	15.05	20.96	19.13	21.38	23.69	26.02
Thousands of feedlot acres	9.99	11.54	12.69	14.20	15.79	17.27
Northern Plains						
Millions of cattle marketed and fraction of national total (%)	3.18 (21)	5.56 (24)	6.39 (25)	7.14 (25)	7.91 (25)	8.69 (25)
Millions of tons of waste deposits	9.17	16.02	18.39	20.55	22.77	25.01
Thousands of feedlot acres	6.08	10.63	12.20	13.63	15.11	16.60
High Plains						
Millions of cattle marketed and fraction of national total (%)	1.07 (7)	2.71 (12)	4.58 (18)	5.12 (18)	5.67 (18)	6.23 (18)
Millions of tons of waste deposits	3.08	7.79	13.19	14.74	16.33	17.94
Thousands of feedlot acres	2.05	5.17	8.75	9.78	10.84	11.90
United States						
Millions of cattle marketed	14.96	23.04	25.70	28.72	31.82	34.96
Millions of tons of waste deposits	43.08	66.36	74.01	82.70	91.64	100.68
Thousands of feedlot acres	27.39	42.35	47.36	52.94	58.68	64.44

SECTION 1
INTRODUCTION

POLLUTION SOURCES ANALYZED

This report describes preliminary research towards the development of a methodology for the estimation of kinds, amounts and trends of groundwater pollution from the activities of man, and the illustrative application of this methodology to selected activities which represent important potential sources of groundwater pollution. The results of these analyses consist of estimates—over time—of the volumes and the areal coverage of potential groundwater pollutants. Given these estimates, geohydrological analyses may be employed to infer the extent to which the activities considered could contribute to groundwater degradation in specific situations.

The activities for which preliminary analyses were performed are the pulp and paper industry, the petroleum refining industry, the primary metals industries, phosphate rock mining, and two major agricultural activities, fertilizer use and cattle feedlots. Taken together, these comprise a broad spectrum of the types of activities which may affect groundwater quality, and thus serve to demonstrate the applicability of the approach to a diversity of activities. Additionally, these activities embrace examples of point source as well as a nonpoint source (agricultural fertilizer) of potential groundwater pollution and therefore provide an opportunity for the use of various appropriate types of geohydrological analyses. The industrial activities were selected from among the largest users of industrial water in the United States because the amount of wastewater to be disposed of (in ways which may pollute groundwater, such as lagooning or sedimentation ponds) is usually related to the amount of water taken in for processing operations. In 1968, chemical manufacturing, primary metals production, pulp and paper production, and petroleum refining accounted for 29 percent, 32 percent, 15 percent, and 9 percent, respectively, of total U.S. industrial water intake, totaling about 85 percent. Phosphate rock mining falls within the chemicals manufacture area, and steel production accounts for about 90 percent of U.S. primary metals production. The impact on groundwater quality of the two agricultural activities, fertilizer use and cattle feedlots, are not keyed to their intake of water, but rather to the areas they affect and to the intensity of the activities in these areas.

Estimates were made of the volumes and areal extent of the possible groundwater pollutants from each activity, by census regions for the United States, except for phosphate rock mining. This estimate covered only a small, well-defined area of Florida that accounts for about 64 percent of U.S. phosphate rock production. Although geographically concentrated, this activity was included as a demonstration of the approach in an extractive industry. The analysis could, of course, be repeated to treat other extractive industries concentrated elsewhere.

The choice of activities analyzed in this report does not imply any judgment that they are more important than other potential sources of groundwater pollution which were not included. Further, only tentative conclusions can be drawn regarding the relative importance among the activities herein analyzed, within the context of the broad regional breakdowns employed in this preliminary study. The relative importance of sources may vary greatly from region to region, even within a particular broadly defined activity. For example, with respect to agriculture as a broad activity, in areas of irrigated croplands the principal source of salt input to the soil—and potentially, the groundwater—is often the irrigation water rather than the use of fertilizers which is analyzed in this study.

The value of the approach demonstrated in this study lies primarily in its use of easily available data on man's activities to provide a basis for inferring groundwater quality. This is of special importance because of the long delay—typical of groundwater aquifers—between input of the pollutant and the recognition of the degradation of the resource. For example, pollutants that entered an aquifer, say in 1955, may not be detected at an extraction point until 1980. By relating groundwater pollution to man's activities, both the current and future condition of an aquifer may be inferred. The analysis can be performed for any desired geographic area, recognizing always that the inference may be very approximate unless small areas are considered in detail.

However, from a broad point of view, an important use of the results of the analysis presented here is that even at an aggregated geographic level (ie, region) an inference may be drawn of the geographic areas which may be most susceptible to groundwater pollution from various activities.

In subsequent analyses, the geographic unit of study could easily be made States, or Department of Commerce Business and Economic Areas. This would give a rapid and synoptic view of the geographic incidence of potential pollution from various sources of man's activities.

It cannot be overemphasized that the aim of this report is to present an approach to relating groundwater pollution to man's activities. Numerous assumptions were made when data were not readily available. The reader is invited to change any assumptions he finds implausible, and use the approach to develop numerical estimates of his own.

RATIONALE

The objectives of EPA and the States in implementing the requirements of the Federal Water Pollution Control Act Amendments of 1972 (P.L. 92-500; 86 Stat. 816) are to "prevent, reduce, and eliminate pollution of water resources," "improve their sanitary condition," and "restore and maintain the chemical, physical, and biological integrity" of the Nation's groundwaters. To prevent, reduce, and eliminate pollution requires that the sources of groundwater pollution be identified, and that control and enforcement actions be undertaken on the basis of the severity of pollution and the number of people who would benefit from cleaner waters.

The phrase "monitoring groundwater quality" has almost invariably been used in the sense of taking samples of water from a well and subjecting these samples to chemical and biological analysis. Information describing groundwater pollution is very sparse, and the data that do exist have not been centrally collected and compiled. Because of their sparsity and unreliability it appears that an adequate picture of groundwater pollution could not be drawn from existing data even if the scattered and fragmentary reports were collected and compiled.

In studying the question of how groundwater quality might be assessed most effectively in relation to cost and to best support the development of groundwater quality standards and enforcement procedures, TEMPO soon recognized that "monitoring" must be used in a much broader sense than simply analyzing samples of groundwater, and inferring the state of the aquifer from these samples. This recognition is based on some of the facts of groundwater hydrology:

- Groundwater moves so slowly (the average rate ranges from 5 feet per day to 5 feet per year) that contaminants may not be detected at sampling points for years or decades after they enter the ground.
- A water sample from a nonpumped well is representative only of the water in the well; if the well has been pumped, even for a number of years, the water sample may have moved only a few tens of feet during the period of pumping, and the sample

is still representative of only a tiny fraction of the aquifer volume.

- Many contaminants tend to occur in plumes that spread out quite slowly. Thus, samples taken from a particular point in the aquifer are very unlikely to be representative of the aquifer. It follows that groundwater monitoring in the conventional sense of well-sampling is an indirect method, and one that can be relied upon to produce high-confidence results only at very considerable expense, if at all.
- Tracing detected contaminants back to their source—both in space and time—is often very difficult, and may not provide adequate proof of legal culpability.

A major conclusion from these facts is that the detection of pollutants at the point where they enter the ground (which may constitute a violation of regulations, when the regulations impose controls intended to prevent the escape of pollutants into the ground) is the most rapid and effective way to detect and limit the amount of pollution.

This study demonstrates that analysis of man's activities can serve as an alternative approach to sampling groundwater to monitor its quality. It should be noted that this approach may be no more indirect a means of monitoring than the sampling approach which has conventionally been used.

OVERVIEW OF METHODOLOGICAL APPROACH

Available historical data and growth rate projections were used to assess the impact of past, present, and future demographic, economic, and technological factors upon groundwater quality. As indicated earlier, demonstration studies were conducted using the following four industrial wastewater examples and two solid waste examples:

- Pulp and paper manufacturing wastewater
- Petroleum refining wastewater

- Primary metals manufacturing wastewater
- Phosphate mining wastewater
- Commercial fertilizer consumption
- Beef cattle feedlot wastes

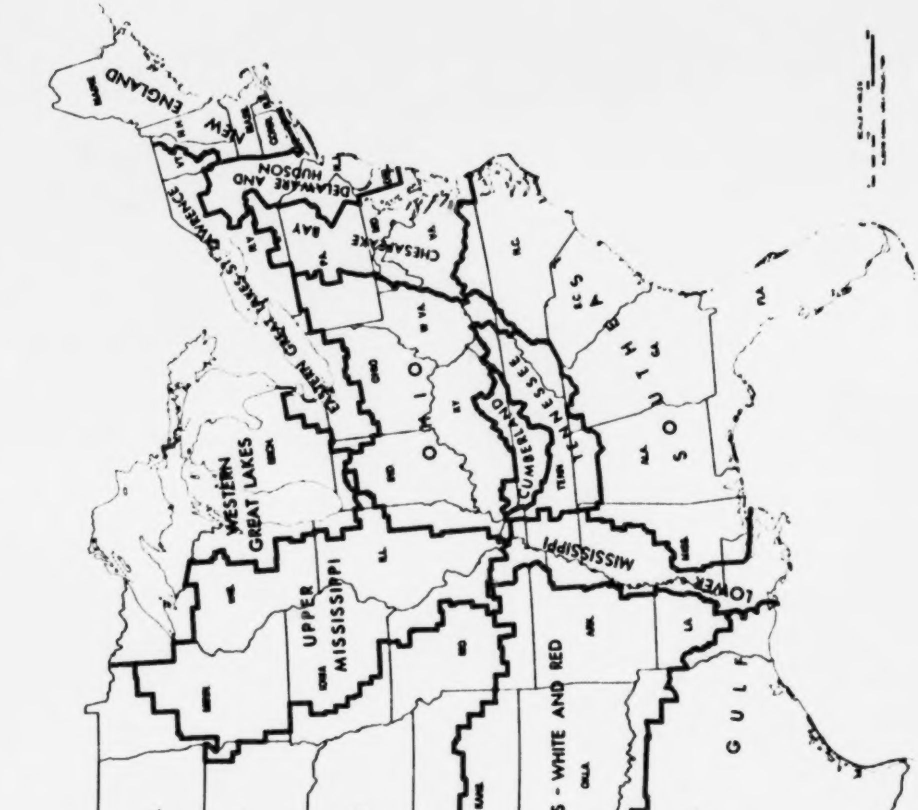
Wastewater Examples

The first three examples are based largely on U.S. Bureau of the Census manufacturing statistics and industry growth forecasts by the University of Maryland's Bureau of Business and Economic Research.[1] The fourth is based primarily upon U.S. Bureau of Mines data.

The estimates are segregated by U.S. Bureau of the Census Industrial Water Use Regions (see Figure 1) except in the case of phosphate rock mining, since this latter industry is concentrated in a single county in central Florida. Because of the highly aggregate nature of the data they are meant only to reflect orders of magnitude and in the case of projections, only trends. Their use is intended to be limited to suggestions for further research and not as regulatory guidelines, nor as definitive indications of the hazard from these activities. For example, the potential harm that might be caused by groundwater pollution in a very concentrated, populous area is obviously greatly different from the same amount spread over a wide area.

In addition to the uncertainty due to aggregations, more uncertainty arises from the limited amount of data collected. In order to confidently estimate pollution in groundwater not only is it necessary to know the diffusion properties of the polluted water after it enters an aquifer, but also to have information concerning soil properties and wastewater engineering practices of the industries in question. The data collected did not encompass all of these needs.

Of major interest in the wastewater studies were treatment practices that use unlined earthen pits to contain wastewater and their waste solids, possibly allowing wastes to seep into underground aquifers. The


NEW ENGLAND
DELAWARE AND HUDSON
CHESAPEAKE BAY
EASTERN GREAT LAKES ST. LAWRENCE
WESTERN GREAT LAKES
OHIO
CUMBERLAND
TENNESSEE
SOUTH
UPPER MISSISSIPPI
LOWER MISSISSIPPI
MISSOURI
ARKANSAS - WHITE AND RED
WESTERN GULF
COLORADO
GREAT BASIN
PACIFIC NORTHWEST
CALIFORNIA

Source: U.S. Bureau of the Census

Figure 1. Industrial water use regions.

two relevant practices were unlined sedimentation and lagooning. The first, unlined sedimentation, is used to remove suspended solids. The water is contained in an unlined basin and the solids are settled out. This purely physical treatment is also called primary treatment. In the second, the water sits in a shallow pond and the bacteria which the water contains combine with oxygen from the air to stabilize the waste products remaining after primary treatment. This biological treatment is also called secondary treatment. Because of the relatively short detention time of the water for sedimentation as compared to lagooning—and thus the lesser containment capacity required—unlined sedimentation constitutes a lesser threat to groundwater integrity.

The major relevant parameters for estimating infiltration potential from these wastewater treatment practices are the following:

1. Constituents of the wastewater which might migrate into the underground water supply
2. Aquifer structure of proximate area
3. Soil composition
4. Containment time for water treatment
5. Area covered by water (or by empty lagoons, etc, waiting to be cleaned)
6. Degree to which lagoon or sedimentation basin seals itself.

Constituents and their concentrations were found for the most part from The Cost of Clean Water.[2] In most cases total wastewater as given by Cost was divided into total wasteload of a specific constituent to obtain the concentration. This, of course, varies from case to case; but only an average could be obtained. The concentration becomes even more uncertain in the case of a multistep production process in which different waterborne wastes are generated according to steps, since the wastes may be treated together. Depending on the assumptions made, the estimated concentrations could vary greatly.

The waste constituents for which the water is being treated, BOD (biochemical oxygen demand) or suspended solids, are not necessarily of interest. Those of concern are total solids dissolved in the water (TDS) and constituents such as cyanide,* arsenic, cadmium, zinc, etc. These are the pollutants which may find their way into groundwater under certain geological and hydrological conditions. While peculiar geological and hydrological factors in each of the regions were not studied, it may be germane to point out, for example, that the Southeast, a region in which lagooning is a widespread practice, has a high water table which greatly increases the potential for groundwater pollution.

On the basis of conversations with sanitary engineers,† the wastewater studies assumed a seepage rate of 30 inches per year for unlined lagoons and ponds used in all industries and regions. The limiting factors are the soil and the sealing activity of the waste treatment bottom. This sealing activity is rather uniform; thus the assumption of a constant infiltration rate may not be too far off. However, a few months are required for a new lagoon or basin to seal itself, during which time a high seepage rate exists. This seepage rate will obviously depend on the characteristics of the soil. Moreover, since lagooning as a widespread practice is a relatively recent phenomenon, presealant seepage has probably not been negligible. Because of the sketchiness of the data, however, variation in the seepage rate was not taken into account in any systematic way.

The finalized data are in the form of volume of wastewater treated and acreage covered continuously by water being treated by the various processes. For sedimentation basins, the algorithm used to estimate acreage is the following: obtain total water being treated per year from

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*Secondary treatment actually reduces cyanide level.

†Notably Professor P. H. McGauhey, Sanitary Engineering Research Laboratory, University of California at Berkeley.

Census of Manufactures[3,4] and estimate the portion that is treated. Assuming that each industry operates 300 days per year, divide 300 into total water treated to estimate the total water dumped into basins each day. Divide by two to account for one-half day of treatment time. To obtain acreage covered, divide daily volume by 7.5 to obtain cubic feet of water, divide cubic feet by the basin depth (assumed to be 8 feet for sedimentation basins), and finally divide the resulting square feet of coverage by square feet per acre (43,560). For lagoons, the calculation is similar but the volume must be increased by the number of days the wastewater is retained. Based on an average pond depth of 4 feet, a detention time of 20 days was assumed (on the basis of personal contact,* Paper Profits,[5] Wastewater Engineering,[6] etc). Thus, the calculation was as follows:

$$\text{Gallons lagooned/year} \div 300 \text{ days/year} = \text{gallons lagooned/day},$$

and

$$\text{Gallons lagooned/day} \times 20 \text{ days} \div 7.5 \text{ gallons/cubic ft} \div 4 \text{ ft depth} \div 43,560 \text{ ft}^2\text{/acre} = \text{acreage covered.}$$

However, this calculation assumes 20 separate lagoons to avoid holding some water for more than 20 days. Also, some excess lagoon capacity must be available to allow for cleaning, and some time is required to fill and empty the lagoons.† Because of these latter considerations, after arriving at acreage by the aforementioned method, an extra 50 percent was added for the steel and petroleum wastewater cases;

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*P.H. McGauhey.

†Neglecting drainage times, exactly 50 percent excess capacity would be necessary employing three lagoons of 10 days' capacity each. Lagoon 1 would be filled from days 1 through 10 and the effluent held through day 30. Lagoon 2 would be filled from days 11 through 20 and the effluent held through day 40. Lagoon 3 would be filled from days 21 through 30, after which lagoon 1 would again be available for filling.

the extra capacity was neglected in the paper wastewater case. The omission is not critical because varying detention times, depths, wastewater engineering processes, climate, etc, render these results very approximate and aggregative at best.

Aside from estimating present acreage covered, wastewater volumes were projected forward to 1983 and backward to 1954. As more and more water receives treatment in unlined basins and lagoons, the threat to groundwater increases because of larger seepage areas. In most cases the 1968 figures from the 1967 Census of Manufactures[4] were used for a base and 1977 (the EPA deadline for best practicable technology) was assumed to be the year in which all wastewater had to undergo secondary treatment. In the pulp and paper industry, for instance, in 1968 about 34 percent of total wastewater underwent treatment. In 1977 100 percent is assumed to be treated, and interpolations were used for the interim years. When supportable by the available data, different projections were made for different regions.

In addition to considering amounts of water treated, assumptions were made in regard to changes in treatment technology. For instance, as more lagoons become lined and aerated and more water is treated by alternate methods, deeper lagoons, shorter detention times, and a smaller amount of water lagooned in relation to total water receiving secondary treatment can be assumed.

Detailed results of the pulp and paper, petroleum refining, and primary metals manufacturing wastewater studies are given in Sections 2, 3, and 4. The phosphate mining wastewater study is described in Section 5.

Solid Waste Examples

The commercial fertilizer and feedlot waste examples generally follow a similar methodological approach to that employed in the liquid-waste studies. Both employ statistical data prepared by the Bureau of the Census and the U.S. Department of Agriculture to define past conditions, both are based on regions defined by the Bureau of the Census, and both employ growth forecasts from the University of Maryland's Bureau of Business and Economic Research in order to project future trends.

Like the industrial wastewater examples, the fertilizer and feedlot examples employ certain assumptions: the results are intended only to indicate orders of magnitude and trends and to demonstrate a methodology and suggest areas for further work. The nine fertilizer-using regions and the eleven cattle feeding regions used in these studies are doubtless too aggregated to furnish data upon which to base regulatory action. But again, even at this level of aggregation it may be useful to note, for example, that the South Atlantic fertilizer consuming region is projected to apply more fertilizer tonnage per acre by 1985 than any other region in the United States, and this region is roughly equivalent in its boundaries to the Southeast industrial water use region with its intensive industrial wastewater lagooning activity.

Neither the fertilizer nor the feedlot waste study attempts to define the groundwater pollution potential of these substances, but only to demonstrate a possible approach to determine in a gross way what past, present, and future concentrations of pollutants may exist and at what rate the condition may be intensifying. To carry the analyses further requires more disaggregation and additional data (eg, on rainfall, which may be an important determinant of the pollution potential of some solid wastes), and expert geological and hydrological judgments. The detailed results of the fertilizer and feedlot waste investigations are described in Sections 6 and 7, respectively.

Estimation of Groundwater Infiltration

The methodology employed in the demonstration studies described in this report yields estimates of past and projected potential groundwater pollutants based on economic growth and technological change. A hydrological analysis is required to derive the actual groundwater pollution which may be caused by these potential pollutants.

The following demonstrates a first-approximation approach to estimating the extent to which liquid wastes can infiltrate and pollute aquifers, using as an example leachate from an urban landfill. Clearly, the results can be made more explicit and more reliable by incorporating more specific data.

Consider a hypothetical groundwater basin in the Eastern United States with an area of 1,000 square miles. The area is largely urbanized, with a population of some 2 million persons. Assuming a landfill for every 20,000 persons, a total of 100 landfills are distributed within the area.

To determine the effect of landfills on groundwater quality, assume that:

- The average landfill has an area of one million square feet (1,000 by 1,000 feet, or 23 acres)
- Ninety percent of the existing landfills have no controls to prevent leakage and hence are capable of generating leachate
- Annual precipitation averages 36 inches per year and 50 percent (or 18 inches) of this infiltrates into the landfills and emerges as leachate.

On the basis of the above assumptions, the leachate generated by one landfill will amount to

$$10^6 \text{ ft}^2 \times 1.5 \text{ ft/yr} \times 7.48 \text{ gal/ft}^3 = 11 \times 10^6 \text{ gal/yr.}$$

This volume of leachate mixes in most cases with the groundwater contained in the shallow unconfined aquifer underlying the landfill. For estimating purposes let the actual groundwater velocity be 3 feet per day. The leachate can be assumed to mix by dispersive action within the top

10 feet of the groundwater body below the water table. With an aquifer porosity of 0.33, this provides an available groundwater dilution volume of

$$1,000 \text{ ft} \times 10 \text{ ft} \times 0.33 \times 3(365)\text{ft/yr} \times 7.48 \text{ gal/ft}^3 = 27 \times 10^6 \text{ gal/yr.}$$

Bacterial pollution can be neglected so that only chemicals in solution need be considered. If the initial concentration of total dissolved solids in the leachate averages 5,000 mg/l, and if the mixing of the leachate within the top 10 feet of groundwater is complete, the resulting increase in pollutant concentration of the groundwater will amount to

$$\frac{11(5,000)}{(11 + 27)} = 1450 \text{ mg/l.}$$

This concentration (plus that of the native groundwater) would be expected in a shallow monitor well located immediately downstream from the landfill. At greater distances downstream the concentration will gradually diminish by dispersion and dilution. In a typical situation the plume of polluted groundwater might extend 5,000 feet from a landfill– either to a surface water body receiving groundwater outflow or to a point where the concentration was considered acceptable in terms of water quality criteria. The area affected could then be estimated as

$$1,000 \text{ ft} \times 5,000 \text{ ft} = 5 \times 10^6 \text{ ft}^2, \text{ or } 115 \text{ acres.}$$

Extending the above reasoning for a single landfill to the entire groundwater basin, the total number of landfills contributing leachate to groundwater would equal 90. The total volume of groundwater degraded would amount to

$$90 \times (11 + 27) \times 10^6 \text{ gal/yr} = 3.4 \times 10^9 \text{ gal/yr.}$$

This volume represents the estimated annual production rate of polluted groundwater due to landfills.

The gross area subject to groundwater pollution from landfills would be equal to

$$\begin{aligned} 100(23) + 90(115) &= 12{,}650 \text{ acres} \\ &= 19.8 \text{ square miles.} \end{aligned}$$

Stated another way, landfills in the hypothetical basin occupy only 0.36 percent (3.6 square miles) of the gross land area in the basin, but they adversely affect groundwater quality underlying 1.98 percent (19.8 square miles) of the basin.

The type of hydrological analysis employed above has the advantage of being a relatively rapid and easy method for arriving at gross estimates of groundwater pollution concentrations, volumes, and areas. It has the disadvantage of all approximations; namely, it may be misleading in specific applications unless refined by using more specific information and improving the estimates on a case-by-case basis, or at least on the basis of a number of categories of landfills, wastes, construction methods, and local hydrological conditions (including soil and underlying aquifer materials).

Some of the techniques used in the context of the landfill illustration are employed in the analyses of Sections 2 through 7 to give a rough indication of the probable importance of potential groundwater pollutants from various sources. However, it cannot be emphasized too strongly that the results are very approximate. Far more detailed and specific data and analyses are necessary to make decisions regarding regulation, monitoring, and enforcement actions. The intent at this stage is to demonstrate methodology, not to produce quantitative results.

SECTION 2

PULP AND PAPER INDUSTRY WASTEWATER

INTRODUCTION

In 1968 the pulp and paper industry discharged 2,078 billion gallons of wastewater and was responsible for one-fourth of all industrial effluent treated in lagoons in the United States. This total effluent output by the pulp and paper industry represented an increase of 28 percent over that of 1954, and is about one-half of the expected discharge in 1983. Pulp and paper manufacturing is a significant industry in most, but not all, of the 18 Industrial Water Use Regions (Figure 1).

Two types of wastewater treatment are commonly employed: "primary," or sedimentation, treatment to settle out suspended solids, and "secondary" treatment for the reduction of biological oxygen demand (BOD) through bacterial action to stabilize waste products. Generally, BOD treatment occurs after wastewaters have been subjected to sedimentation treatment. In a few paper-manufacturing regions of the country sedimentation treatment is accomplished in unlined earthen basins, while lagooning for BOD reduction is used in all areas.

Lagoons receive greater volumes of wastewater, require more time to dispose of their wastes and occupy more extensive acreage than do unlined sedimentation basins in this industry. In 1954, 86 billion gallons of effluent were treated in lagoons covering 4,400 acres, while 84 billion gallons were processed in unlined sedimentation basins covering only 54 acres. In 1968, the figures were 466 billion gallons and 24,000 acres for lagooning, with 212 billion gallons and 135 acres for unlined sedimentation. As discussed subsequently in this section, the industry is projected by 1983 to process 1,864 billion gallons of wastewater covering 73,000 acres in lagoons, and 99 billion gallons covering 63 acres in unlined sedimentation basins. These figures indicate the divergence over time of increase in effluent treated from the more modest increases in total effluent.

The greatest concentration of pulp and paper industry lagooning and unlined sedimentation basin processing in the United States is in the Southeast region, with substantial volumes and areas also evident in the Pacific Northwest, Arkansas, New England, and the Western Great Lakes regions. According to Paper Profits,[5] lagooning is used extensively in all regions of the country having significant pulp and paper industry activity. Unlined sedimentation is used extensively only in the Chesapeake Bay, Southeast, and Pacific Northwest regions, with the other paper-producing regions using different primary treatment techniques.

The effluent from these lagoons and basins is a possible groundwater contaminant, since it contains 0.012 pounds per gallon of TDS (total dissolved solids)[2] and may infiltrate underlying groundwater. Generally, the TDS content is composed of lignins, wood sugars, sulfates, sulfites, calcium compounds, grease, and color. Since the TDS content of the effluent is not significantly affected by sedimentation or lagooning, a homogeneous batch of wastewater—in terms of its possible impact on groundwater quality—can be assumed for both these treatment processes. Based on conversations with sanitary engineers, the infiltration rate of this effluent from unlined basins and lagoons into underlying groundwater is estimated to be 30 inches per year. This figure may vary by as much as a factor of 10, depending on local soil conditions, self-sealing, and presealant leakage.

The following subsections discuss the assumptions made and the analytical approach used in projecting the volume of wastewater for unlined sedimentation and lagooning. Standard Industrial Code (SIC) 26, "Paper and Allied Products," was used in gathering information from Census of Manufactures.[3,4] The regional volumes of and the areas covered by the two treatment methods are reviewed and the total volume of wastewater discharged nationally by the industry is presented.

APPROACH

Five factors were considered in the projections of the volume of wastewater in unlined sedimentation basins and lagoons and several assumptions were made accordingly.

The first factor was the growth of the industry's production output. The following estimates of the annual growth rates for 1971-1983 were obtained from the University of Maryland, Bureau of Business and Economic Research.[1]

Year	Percent/Year
1971-1973	5.73
1974-1975	6.55
1976-1978	5.36
1979-1983	2.21

The 1968-1971 growth rate was assumed to be the same as that shown in the projections for 1971-1973.

The second factor considered was possible variation in water-usage per unit of output. None of the references consulted anticipated any lower usage or more recycling within the projection period. Thus, the wastewater discharged (as opposed to wastewater treated) by the industry was assumed to grow at the same rates as those shown for production output. Table 1 shows the past and projected volume of wastewater discharged from 1954-1983. The historical data (1954-1968) shown in the table are taken from Census of Manufactures.[3,4] The data were listed by region for 1964 and 1968, but only national totals were available for 1954 and 1959. For these earlier two periods the regional discharge shares are assumed to be the same as for 1964 and the total industry

Table 1. Total wastewater discharged by the pulp and paper industry in 15 Industrial Water Use Regions, 1954–1983, and total treated before discharge, 1964 and 1968 (billions of gallons).

Region	1954[a]	1959[a]	1964[b]		1968[c]		1971[d]	1973[d]	1975[d]	1977[d]	1983[d]
			Total discharged	Total treated	Total discharged	Total treated					
New England	194	214	226	29	246	37	295	330	374	414	487
Delaware and Hudson	146	165	118	28	69	28	74	82	94	104	122
Chesapeake Bay	97	104	113	47	101	49	123	137	156	173	203
Eastern Great Lakes	81	87	87	27	66	17	74	82	94	104	122
Ohio River	49	52	51	21	49	31	49	55	62	69	81
Tennessee	65	70	66	30	64	33	74	82	94	104	122
Southeast	421	467	512	231	601	330	712	796	904	1,001	1,176
Western Great Lakes	130	145	154	61	163	66	196	220	249	276	324
Upper Mississippi	97	95	110	35	124	19	147	165	187	207	243
Lower Mississippi	32	31	31	3	57	12	74	82	94	104	122
Missouri	16	20	1	-	-	-	-	-	-	-	-
Arkansas	49	60	67	66	79	78	98	110	125	138	162
Western Gulf	16	18	28	22	51	51	49	55	62	69	81
California	16	25	24	17	44	22	49	55	62	69	81
Pacific Northwest	227	248	325	88	312	127	368	412	468	518	608
United States	1,620	1,824	1,942	707	2,078	915	2,456	2,746	3,118	3,451	4,056

Notes:

[a] 1954 and 1959 national data from Reference 3; regional distribution assumed to be the same as that for 1964 since no data were available.

[b] Regional and national data from Reference 3; regional figures do not sum exactly to national totals.

[c] Data from Reference 4.

[d] Assumes same regional distribution as 1968; growth projections based on Reference 1.

discharge allocated accordingly. The national projections for wastewater discharge for 1971-1983 are based on the above industry growth rates from Reference 1, while the regional projections assume that the 1968 regional distribution will remain unchanged through 1983.

The third consideration was possible changes in the amount of wastewater undergoing primary treatment as a percentage of the total discharged by the industry. This was reviewed only for the three regions shown in Table 2, as none of the other thirteen regions examined was using unlined sedimentation basins for primary treatment. The 1964 and 1968 data were taken directly from Census of Manufactures. The backward projections for 1954 and 1959 assume that, since water pollution regulations were less stringent in those years than in 1964, the approximate percentages of water treated in 1954 and 1959 were respectively 20 percent and 10 percent lower than in 1964. The 1971-1983 projections assume that these particular three regions will comply with the EPA requirement to treat 100 percent of all wastewater prior to discharge by 1977.[2] Each region is projected to achieve 100 percent treatment by 1977 in increments that depend upon 1968 treatment percentages.

The fourth factor considered in the projections was possible changes in waste-treatment technology. The references reviewed indicated that industry use of the "best available" technology by 1983 will tend to stem the rise of unlined sedimentation and lagooning. The former is considered a "primitive" treatment process, while the latter is considered an "advanced"* method. Thus, in addition to total percentages of primary treatment, Table 2 shows for three regions the percentages of primary treatment accomplished in unlined basins for 1954-1983, the 1968 data for which are taken from Paper Profits.[5] In projecting back from 1968 to

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*But only in the context of today's technology. EPA 1983 requirements will probably relegate unlined lagoons to something less than an "advanced" treatment technique.

Table 2. Estimated percentages of pulp and paper industry total wastewater discharged receiving primary treatment and estimated percentages of primary treatment achieved in unlined sedimentation basins, 1954–1983.

Region	1954	1959	1964	1968	1971	1973	1975	1977	1983
Chesapeake Bay									
Total % treated[a]	22	32	42	49	70	85	95	100	100
% treated in unlined basins[b]	45	40	35	30	25	20	15	10	5
Southeast									
Total % treated[a]	25	35	45	55	75	90	95	100	100
% treated in unlined basins[b]	65	60	55	50	40	30	20	10	5
Pacific Northwest									
Total % treated[a]	7	17	27	41	65	85	95	100	100
% treated in unlined basins[b]	40	35	30	25	21	18	14	10	5

Notes:

[a] 1964 and 1968 data from References 3 and 4; a 10% per 5 years decrease from 1964–1954 is assumed in total percentage of wastewater treated because of less stringent pollution regulations.

[b] 1968 data from References 2 and 5; for wastewater treated, 5% and 10% more is assumed treated in unlined sedimentation basins in 1959 and 1954, respectively, because of the state of treatment technology, and the EPA requirement of "best available technology" by 1983 is assumed to virtually rule out unlined basins.

1954, the percentages of wastewater treatment in unlined sedimentation basins were increased by 5 percent per 5 years to reflect the more primitive state of treatment technology. The 1971–1983 projections assume that by 1983 EPA requirements will virtually eliminate the use of unlined basins in the three regions. Each of the regions was projected individually, depending upon its 1968 percentage.

Since secondary treatment of wastewater by lagooning was an advanced process in the earlier part of the period covered by this study, the 1954–1964 estimates contained in Table 3 assume that the percentages of total effluent treated in each region by lagooning were less than they were in 1968. For 1954, 1959, and 1964 these were assumed to be 25, 50, and 75 percent of the 1968 lagooning percentages, while the 1971–1977 projections assume that the percentage of total effluent treated by lagooning will increase to approximately 50 to 60 percent by 1977.[2] Both of these projections were made individually for each region, depending

Table 3. Estimated percentages of total wastewater discharged receiving secondary treatment in lagoons in the pulp and paper industry, 1954–1983.

Region	1954[a]	1959[a]	1964[a]	1968[b]	1971	1973	1975	1977[c]	1983[c]
New England	0.3	0.5	0.8	1.	10.	20.	40.	60.	50.
Delaware and Hudson	3.	6.	9.	12.	25.	40.	55.	60.	60.
Chesapeake Bay	6.	11.	17.	22.	30.	35.	40.	40.	40.
Eastern Great Lakes	2.	4.	5.	7.	20.	35.	50.	60.	50.
Ohio River	3.	6.	8.	11.	16.	35.	45.	55.	50.
Southeast	11.	22.	33.	44.	50.	60.	65.	65.	50.
Western Great Lakes	4.	8.	11.	15.	20.	35.	55.	60.	50.
Upper Mississippi	0.2	0.4	0.6	0.8	10.	20.	50.	60.	50.
Arkansas	24.	49.	73.	97.	98.	96.	94.	92.	86.
Western Gulf	12.	24.	35.	47.	55.	60.	70.	70.	60.
Pacific Northwest	3.	6.	8.	1.	20.	30.	50.	60.	50.

Notes:

[a] Past projections assume progressive 25 percent decreases in lagooning.

[b] Data from Reference 4.

[c] Based on estimates from Reference 2.

upon its 1968 percentage. Finally, the 1983 projections assume that simple lagooning will not be considered the "best available" technology in 1983, and so will not satisfy the EPA's 1983 requirements.[2] Thus, all of the regional percentages for 1983 were either slightly reduced to reflect more advanced technology or were maintained at their 1977 levels.

The fifth factor was whether the industry exhibits any significant seasonality of production, as this could affect the capacity requirements for sedimentation basins and lagoons. Since no production peaks seem to exist, it was assumed that basin and lagoon capacities need be sufficient only for uniform production, wastewater discharge, and treatment schedules in any given year.

REGIONAL POLLUTION IMPLICATIONS

Unlined Sedimentation Basins

The estimated volume of, and area covered by, wastewater in unlined sedimentation basins in the three regions employing this practice are shown in Table 4. From 1954–1983, the Southeast is shown in the table to have several times the volume and acreage of either of the other two regions, with the Chesapeake Bay region having the smallest volume and acreage. The year in which the greatest volumes and acreages for the three regions are expected is 1973, while 1975–1983 reflect a significant reduction in both parameters due to adoption of more advanced treatment methods.

At the assumed infiltration rate of 30 inches per year, for 1973 the Chesapeake Bay, Southeast, and Pacific Northwest regions show an infiltration potential of 37, 342, and 100 acre-feet of wastewater per year, respectively. By 1983, the infiltration potential is projected to drop to 15, 95, and 50 acre-feet per year.

Lagoons

The volume of, and acreages covered by, wastewater lagoons in various regions employing this treatment process are shown in Table 5.

Table 4. Volume and area of wastewater in pulp and paper industry in unlined sedimentation basins, 1954–1983.

Region	1954	1959	1964	1968	1971	1973	1975	1977	1983
Chesapeake Bay									
billions of gallons	9	13	17	15	22	23	22	17	10
hundreds of acres	0.06	0.08	0.11	0.10	0.14	0.15	0.14	0.11	0.06
Southeast									
billions of gallons	68	98	127	165	214	215	172	100	59
hundreds of acres	0.43	0.62	0.81	1.05	1.36	1.37	1.10	0.64	0.37
Pacific Northwest									
billions of gallons	6	15	26	32	50	63	62	52	30
hundreds of acres	0.04	0.10	0.16	0.20	0.32	0.40	0.39	0.33	0.19
United States									
billions of gallons	84	126	170	212	286	301	256	169	99
hundreds of acres	0.54	0.80	1.08	1.35	1.82	1.92	1.63	1.08	0.63

Sources: Tables 1 and 2; References 2, 3, and 4.

From 1954-1983, the Southeast has a much greater volume and area than any other region for lagoons as well as for unlined sedimentation. Other regions expected to have relatively large volumes and areas in lagoons from 1971-1983 are:

- New England
- Western Great Lakes
- Arkansas
- Pacific Northwest.

Most of the urban, colder regions of the country show a steady increase in volume of wastewater lagooned from 1971-1977. Acreage for these regions from 1975-1983 either increases much more gradually than volume or decreases because it has been assumed that increased use will be made of aerated lagoons (assumed to be 6 feet deep, with a detention period of 18 days) in these regions. This will decrease acreage requirements and treatment-cycle times. The volume-to-area ratio in

Table 5. Volume and area of wastewater in pulp and paper industry lagoons, 1954–1983.

Region	1954	1959	1964	1968	1971	1973	1975	1977	1983
New England									
billions of gallons	<1	1	2	2	30	66	150	248	244
hundreds of acres	0.3	0.5	1	1	15	34	45	76	75
Delaware and Hudson									
billions of gallons	4	10	11	8	19	33	52	62	73
hundreds of acres	2	5	6	4	10	17	16	19	22
Chesapeake Bay									
billions of gallons	6	11	19	22	37	48	62	69	81
hundreds of acres	3	6	10	11	19	24	19	21	25
Eastern Great Lakes									
billions of gallons	2	3	4	5	15	29	47	62	61
hundreds of acres	1	2	2	3	8	15	14	19	19
Ohio River									
billions of gallons	1	3	4	5	8	19	28	38	41
hundreds of acres	0.5	2	2	3	4	10	9	12	13
Southeast									
billions of gallons	46	103	169	264	356	478	588	651	588
hundreds of acres	23	53	86	135	182	244	300	332	300
Western Great Lakes									
billions of gallons	5	12	17	24	39	77	137	166	162
hundreds of acres	3	6	9	12	20	39	42	51	50
Upper Mississippi									
billions of gallons	<1	<1	<1	1	15	33	94	124	122
hundreds of acres	-	0.2	0.4	0.5	8	17	29	38	37
Arkansas									
billions of gallons	12	29	49	77	96	106	118	127	139
hundreds of acres	6	15	25	39	49	54	60	65	71
Western Gulf									
billions of gallons	2	4	10	24	27	33	43	48	49
hundreds of acres	1	2	5	12	14	17	22	24	25
Pacific Northwest									
billions of gallons	7	15	26	34	74	124	234	311	304
hundreds of acres	4	8	13	17	38	63	72	95	93
United States									
billions of gallons	86	191	311	466	716	1,046	1,553	1,906	1,864
hundreds of acres	44	100	159	240	367	534	628	752	730

Sources: Reference 4 and Table 3.

the warmer, more rural regions is projected to show less change; for purposes of the projections these were assumed to remain 4 feet deep with a detention period of 20 days.

Table 5 shows that despite increased use of aeration, beginning in 1975 lagoon acreage in some regions continues to exhibit a general increase due to the increased volumes of wastewater. The declines in lagooning acreage between 1977 and 1983 in some regions are explained by the substitution of other treatment methods for lagooning.

A comparison of the figures in Table 4 with those in Table 5 indicates that unlined sedimentation basins occupy up to hundreds of times less area per gallon of effluent treated than do lagoons. This is due to the greater wastewater depth and shorter detention time employed in sedimentation. The difference between the volume-to-area relationship of each treatment method is apparent in the 1968-1983 data for the three regions of the country which employ both types of treatment processes: the Chesapeake Bay, the Southeast, and the Pacific Northwest. During this 15-year period, Tables 4 and 5 reveal the following volume and area relationships of lagooning to unlined sedimentation:

- Chesapeake Bay
  - 1968 volume 1.5 times greater, area 110 times greater
  - 1983 volume 8 times greater, area 400 times greater
- Southeast
  - 1968 volume 1.6 times greater, area 130 times greater
  - 1983 volume 10 times greater, area 800 times greater
- Pacific Northwest
  - 1968 volume equal, area 85 times greater
  - 1983 volume 10 times greater, area 500 times greater.

The foregoing area relationships highlight the vastly greater infiltration potential of lagoons for a given volume of wastewater treated.

The peak year in the Southeast region for acreage covered, 1971, results in a potential for 45,500 acre-feet per year of wastewater infiltration at the assumed rate of 30 inches per year. In 1977, the peak year for the Northwest region in terms of acreage covered, infiltration would amount to 19,750 acre-feet per year. In this same year, the infiltration amount for the New England region is 15,750 acre-feet per year. While these infiltration projections are at best very approximate, it should also be borne in mind when considering their magnitude that the computations do not include the extra lagoon acreage necessary (approximately 50 percent) for filling and emptying cycles and BOD reduction.

NATIONAL POLLUTION IMPLICATIONS

Table 6 shows the national volume of wastewater discharged, the volume treated before discharge, and the area covered by the treatment processes over the 1954–1983 projection period. The total volume discharged by the industry increased by approximately 25 percent from 1954–1968, and is projected to double from 1968–1983. The rates of increase in the future, however, are expected to reflect the projected rates of growth of production output and so will be slowly decreasing.

The volume and area covered by wastewater in unlined sedimentation basins from 1954–1968 increased by a factor of approximately two and one-half, while from 1968–1983 they decrease by approximately one-half.

The volume and area covered by wastewater in lagoons from 1954–1968 increases by approximately five times. From 1968–1983, the volume lagooned increases fourfold, while the area covered by the process increases threefold. The 1983 volume and area figures, however, show a slight decline from 1977, representing technological improvements in treatment.

Table 6. Volume of pulp and paper industry wastewater discharged, volume treated before discharge, and area covered by treatment process, 1954–1983.

Item	1954	1959	1964	1968	1971	1973	1975	1977	1983
Annual growth rate of industry (%)[a]	-	-	-	-	5.73	6.55	5.36	5.36	2.21
Total wastewater discharged (billions of gallons)	1,620[b]	1,824[c]	1,942[c]	2,078[c]	2,456	2,746	3,118	3,451	4,056
Volume of wastewater in unlined sedimentation basins (billions of gallons)	84[b]	126[c]	170[c]	212[c]	286	301	256	169	99
Volume of wastewater in lagoons (billions of gallons)	86	191	311	466[c]	716	1,046	1,553	1,906	1,864
Area covered by wastewater in unlined sedimentation basins (hundreds of acres)	0.5	0.8	1.1	1.4	1.8	1.9	1.6	1.1	0.6
Area covered by wastewater in lagooning (hundreds of acres)	44	100	159	240	367	534	628	752	730

Sources:

[a] Reference 1

[b] Reference 3

[c] Reference 4

Tables 1, 4, 5

SECTION 3

PETROLEUM REFINING INDUSTRY WASTEWATER

INTRODUCTION

The petroleum refining industry employs a complex series of interrelated steps, each subprocess yielding a different type of product and liquid effluent. Detailed information describing the wastewater from these several steps is sparse, and no attempt was made in these projections to delineate wastewater treatment by specific production subprocesses of the petroleum refining industry. Wastewater from the industry as a whole was assumed to be homogeneous. The principal constituents of consequence to groundwater quality appear to be oil, ammonia, suspended solids, phenols, spent caustics, and sulfides.[2, 7, 8]

The volumes of petroleum refining wastewater treated vary substantially among the Industrial Water Use Regions. Overall, this industry uses a volume of water in its processes that is comparable to that used by the pulp and paper industry. In 1959, 1964, and 1968 the industry discharged 1,200, 1,320, and 1,220 billion gallons of water, respectively. Approximately 25 percent of the industry's water intake is solely for cooling purposes, of which increasing amounts are being recirculated:* from 1954 to 1964 production output increased approximately 48 percent, while water intake increased only 13 percent.[2] Since cooling water requires treatment only for thermal pollution, the volume of wastewater subject to effluent treatment processes is less than the total volume discharged.[4]

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*A 2-year study, partially funded by EPA, is currently being conducted to find means to increase even further the percentage of petrochemical wastewater that can be recycled.

The primary references used in this effort were the Census of Manufactures[3,4] and The Cost of Clean Water.[2] Standard Industrial Code 29, "Petroleum and Coal Products," was used from References 3 and 4 for 1959, 1964, and 1968 baseline data for wastewater output projections instead of the seemingly more appropriate Subcode 2911, "Petroleum Refining," because SIC 29 was the only industrial entry containing both the regional and national tables. However, since Subcode 2911 accounted in 1959 and 1964 for 97 percent of the volume of water discharged in SIC 29, this did not appear to present a serious problem in developing and demonstrating a methodological approach for monitoring and predicting petroleum refining wastewater output.

As with paper and primary metals manufacturing wastewater, the treatment practices of interest are unlined sedimentation and lagooning, broken down by the Industrial Water Use Regions shown in Figure 1. Use of these two treatment methods appears to be concentrated in the Delaware and Hudson, Western Great Lakes, Western Gulf, and California regions. The same factors described in Sections 1 and 2 were considered in making regional projections into the past and future: industry growth, variations in water usage per unit of production output, changes in amount of wastewater treated as a percentage of the total discharged, and changes in wastewater treatment technology.

APPROACH

University of Maryland Bureau of Business and Economic Research projections[1] of average annual growth rates of production output of the petroleum refining industry were used to estimate the expected output of the petroleum refining industry from 1971-1983. The growth estimates are:

Years	Percent/Year
1971-1973	4.49
1974-1975	3.85
1976-1978	3.43
1979-1983	3.08

These industry growth rate projections indicate an overall growth of 71 percent between 1968 and 1983 in industry output, but in the past production output has increased more rapidly than water intake and wastewater discharged. This divergence was taken into account by assuming a 1968-1983 annual growth rate of 2 percent per year in wastewater discharged, a rate somewhat less than the projected industry output growth. This results in an overall increase in annual wastewater discharged of 35 percent between 1968 and 1983. The 2 percent growth rate was derived as a middle figure between FWPCA[2] and EPA[8] wastewater growth projections. The former suggests a rate of 3.6 percent per year, while the latter suggests an annual growth rate of only about 1.2 percent.

The third factor listed above, changes in the amount of wastewater treated as a percentage of the total amount discharged, is not expected to show the large increase projected in the pulp and paper industry. According to Census of Manufactures[3,4] data, 75 percent of the total volume discharged in 1964 and 1968 received effluent treatment. Except for those regions exhibiting more than 75 percent treatment in 1968, this percentage of the total wastewater discharged was viewed as the maximum amount requiring treatment for effluents throughout the 1968-1983 projection period, because of the large percentage of the water used only for indirect cooling. For those regions reporting effluent treatment of more than 75 percent the percentage was held constant throughout the projection period.*

The fourth factor, changes in treatment technology, is expected to be of significance to the petroleum refining industry due to EPA requirements for 100 percent treatment of (treatable) wastewater before discharge by 1977, and for use of the best "practicable" treatment technology by that year. Decreases are anticipated in unlined sedimentation as clarifiers come into wider use. Technological changes that are expected to affect lagooning beyond 1977 are the adoption of activated sludge processes for BOD reduction and a growing tendency to use aeration in lagoons, allowing greater depths and shorter detention times.

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*The regions reporting more than 75 percent treatment in 1968 could actually show a future decline in percentage of water treated, depending upon the selectivity of their treatment practices. A corollary to this is wastewater treatment in some urban areas where a common system is used to handle both sewage and precipitation runoff.

The calculations made on petroleum refining assumed a constant rate of production, since no large seasonal effluent output variation for this industry is apparent. Thus, capacity estimates for sedimentation basins and lagoons are based on a uniform production schedule over the year, and no excess capacity is allowed for, other than a 50 percent extra capacity factor for lagoon filling and emptying, BOD reduction (see Section 1), and cleaning.

WASTEWATER VOLUME PROJECTIONS

The 1963 Census of Manufactures[3] and 1967 Census of Manufactures[4] were used as a data base for the total volume of wastewater discharged in each region for 1959, 1964, and 1968 and for the treated volumes in 1964 and 1968. These data are given in Table 7 along with estimates for 1954 and projections for 1971-1983.

Data listed in the 1967 Census of Manufactures[4] for "Primary Settling" and "Secondary Settling" and FWPCA estimates were used as a baseline for the volume of wastewater undergoing unlined sedimentation treatment from 1954-1968.

Unlined Sedimentation Basins

For 1967, FWPCA estimated that 40 percent of all petroleum refineries used "earthen basins" and for 1963, 50 percent.[2] These figures were assumed also to be applicable for 1964 and 1968. Although they do not refer to the volume of wastewater thus processed, they are the only such estimates available in the literature reviewed. Therefore, for lack of better data they were assumed to represent that portion of "primary and

Table 7. Total wastewater volume discharged annually by the petroleum refining industry, 1954–1983, and wastewater treated before discharge, 1964 and 1968 (billions of gallons).

Region[a]	1954[b]	1959[c]	1964[c]		1968[d]		1971[e]	1973[e]	1975[e]	1977[e]	1983[e]
			Discharged	Treated	Discharged	Treated					
Delaware and Hudson	316	332	352	247	321	262	341	354	369	384	432
Eastern Great Lakes	57	63	67	40	71	32	75	78	82	85	96
Ohio River	34	38	24	16	29	23	31	32	33	35	39
Southeast	2	2	5	4	25	4	27	28	29	30	33
Western Great Lakes	147	161	192	104	158	71	168	174	181	189	213
Upper Mississippi	10	11	11	8	15	10	16	17	17	18	20
Lower Mississippi	90	94	120	101	124	88	132	137	142	148	169
Missouri	--	--	21	20	19	17	20	21	22	23	26
Arkansas	11	14	15	13	14	13	15	15	16	17	19
Western Gulf	260	277	334	304	334	297	354	369	384	399	450
Great Basin	2	2	2	2	2	--	2	2	2	2	2
California	124	136	138	110	102	93	108	113	117	122	137
Pacific Northwest	2	2	2	2	2	2	2	2	2	2	3
United States	1,130	1,200	1,320	971	1,220	907	1,295	1,347	1,401	1,458	1,642

Notes:

[a] May not add up to national totals due to independent rounding. [b] Assumes same distribution as 1959. [c] Reference 3. [d] Reference 4. [e] Projected 1971-1983 regional and national rates of 2 percent annual increase in total discharge are based on References 2 and 8 and assume same regional distribution as 1968.

secondary settling" accomplished in unlined basins in all petroleum-refining regions of the country, and were used as a baseline for the estimated treatment percentages given in Table 8. Projections for 1954 and 1959 unlined sedimentation treatment were assumed to increase by 5 percent during each period to 60 and 55 percent, respectively. The 1971-1983 treatment projections in Table 8 were based on an assumption of 75 percent treatment (or more, depending upon the 1968 regional percentages) of total wastewater by 1977 for each region in order to meet EPA requirements. The 1971, 1973, and 1975 percentages of wastewater treated in each region were individually projected on the basis of the amount of wastewater treatment that had been achieved in 1968.

Table 9 gives the estimated petroleum refining volume and acreage of wastewater processed in unlined sedimentation basins from 1954-1983. The volume for each region and year was derived from Tables 7 and 8 by multiplying total volume (from Table 7) first by estimated percentage receiving treatment (Table 8), and then by estimated percentage of primary treatment achieved in unlined basins (Table 8). The acreage-covered figures of Table 9 were derived using the algorithm described in Section 1 ($A = 1/2 (V \div 300) \div 7.5 \div 8 \div 43,560$). The figures assume an average depth for sedimentation basins of 8 feet and a detention time of one-half day.

Lagoons

The procedure used for estimating the volume of wastewater that was lagooned from 1954 to 1968 was similar to that for unlined sedimentation treatment. The 1968 figures in 1967 Census of Manufactures[4] for total volume of water discharged (see Table 7) and the lagoon treatment volume estimates from the same source (listed under "Ponds or lagoons") were used to establish percentages of wastewater treated by lagooning in 1968 both regionally and nationally. These percentages are given in Table 10 with 1954-1964 estimates and 1971-1983 projections.

Table 8. Percentages of total wastewater receiving primary treatment and estimated percentages of primary treatment achieved in unlined sedimentation basins in the petroleum refining industry, 1954–1983.

Region	1954	1959	1964	1968	1971	1973	1975	1977	1983
Delaware and Hudson									
Total primary treatment %[a]	36	49	70	82	82	82	82	82	82
% primary in unlined basins[b]	60	55	50	40	35	35	30	25	15
Eastern Great Lakes									
Total primary treatment %[a]	32	41	60	45	53	60	67	75	75
% primary in unlined basins[b]	60	55	50	40	35	35	30	25	15
Ohio River									
Total primary treatment %[a]	27	34	67	80	80	80	80	80	80
% primary in unlined basins[b]	60	55	50	40	35	35	30	25	15
Southeast									
Total primary treatment %[a]	50	65	80[c]	16[c]	31	46	61	75	75
% primary in unlined basins[b]	60	55	50	40	35	35	30	25	15
Western Great Lakes									
Total primary treatment %[a]	31	41	54	45	53	60	67	75	75
% primary in unlined basins[b]	60	55	50	40	35	35	30	25	15
Upper Mississippi									
Total primary treatment %[a]	40	46	73	65	68	70	72	75	75
% primary in unlined basins[b]	60	55	50	40	35	35	30	25	15
Lower Mississippi									
Total primary treatment %[a]	51	70	84	71	72	73	74	75	75
% primary in unlined basins[b]	60	55	50	40	35	35	30	25	15
Missouri									
Total primary treatment %[a]	-	-	95	89	89	89	89	89	89
% primary in unlined basins[b]	-	-	50	40	35	35	30	25	15
Arkansas									
Total primary treatment %[a]	55	64	87	90	90	90	90	90	90
% primary in unlined basins[b]	60	55	50	40	35	35	30	25	15
Western Gulf									
Total primary treatment %[a]	53	71	91	89	89	89	89	89	89
% primary in unlined basins[b]	60	55	50	40	35	35	30	25	15
Great Basin									
Total primary treatment %[a]	-	-	100	-	100	100	100	100	100
% primary in unlined basins	-	-	50	-	35	35	30	25	15
California									
Total primary treatment %[a]	40	53	80	80	80	80	80	80	80
% primary in unlined basins[b]	60	55	50	40	35	35	30	25	15
Pacific Northwest									
Total primary treatment %[a]	50	75	100	100	100	100	100	100	100
% primary in unlined basins[b]	60	55	50	40	35	35	30	25	15
United States									
Total primary treatment %[a]	41	55	74	74	76[d]	78[d]	80[d]	82[d]	82[d]
% primary in unlined basins[b]	60	55	50	40	35	35	30	25	15

Notes:

[a] For percentages of total wastewater receiving primary treatment:

- 1954 and 1959 regional data based on national data from References 3 and 4 using 1964 regional distributions
- 1964 and 1968 regional and national data from References 3 and 4
- 1971-1983 regional and national projections based upon EPA requirement for 100 percent treatment by 1977; regional projections individualized on basis of 1968 treatment status.

[b] For estimated percentages of treatment in unlined basins:

- 1954-1968 figures based on 1950-1967 estimates from FWPCA[2]
- 1971-1975 figures based on FWPCA[2] estimates with 5 percent increases because original estimates appear too optimistic
- 1977-1983 figures based on assumption that unlined basins will not meet EPA's 1983 requirements.

[c] Apparent anomaly due to large increase in discharge between 1964 and 1968 with no reported increase in treatment.

[d] Weighted national averages (% primary treatment × discharge volume summed by year for all regions and divided by total national discharge volume).

Table 9. Volume and acreage of wastewater in unlined sedimentation basins in the petroleum refining industry, 1954–1983.[a]

Region[b]	1954	1959	1964	1968	1971	1973	1975	1977	1983
Delaware and Hudson									
billions of gallons	68	89	123	105	98	102	91	79	53
hundreds of acres[c]	0.43	0.57	0.78	0.67	0.62	0.65	0.58	0.50	0.34
Eastern Great Lakes									
billions of gallons	11	14	20	13	14	16	16	16	11
hundreds of acres[c]	0.07	0.09	0.13	0.08	0.09	0.10	0.10	0.10	0.07
Ohio River									
billions of gallons	6	7	8	9	9	9	8	7	5
hundreds of acres[c]	0.04	0.04	0.05	0.06	0.06	0.06	0.05	0.04	0.03
Southeast									
billions of gallons	< 1	< 1	2	2	3	5	5	6	4
hundreds of acres[c]	<0.01	<0.01	0.01	0.01	0.02	0.03	0.03	0.04	0.03
Western Great Lakes									
billions of gallons	27	36	52	28	31	37	36	35	24
hundreds of acres[c]	0.17	0.23	0.33	0.18	0.20	0.24	0.23	0.22	0.15
Upper Mississippi									
billions of gallons	2	3	4	4	4	4	4	3	2
hundreds of acres[c]	0.01	0.02	0.03	0.03	0.03	0.03	0.03	0.02	0.01
Lower Mississippi									
billions of gallons	28	36	50	35	33	35	32	28	19
hundreds of acres[c]	0.18	0.23	0.32	0.22	0.21	0.22	0.20	0.18	0.12
Missouri									
billions of gallons	-	-	10	7	6	7	6	5	3
hundreds of acres[c]	-	-	0.06	0.04	0.04	0.04	0.04	0.03	0.02
Arkansas									
billions of gallons	4	5	7	5	5	5	4	4	3
hundreds of acres[c]	0.03	0.03	0.04	0.03	0.03	0.03	0.03	0.03	0.02
Western Gulf									
billions of gallons	83	108	152	119	110	115	103	89	60
hundreds of acres[c]	0.53	0.69	0.97	0.76	0.70	0.73	0.66	0.57	0.38
Great Basin									
billions of gallons	-	-	1	-	1	1	1	1	-
hundreds of acres[c]	-	-	<0.01	-	<0.01	<0.01	<0.01	<0.01	-
California									
billions of gallons	30	40	55	33	30	32	28	24	16
hundreds of acres[c]	0.19	0.26	0.35	0.21	0.19	0.20	0.18	0.15	0.10
Pacific Northwest									
billions of gallons	< 1	< 1	1	1	1	1	1	1	-
hundreds of acres[c]	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-
United States									
billions of gallons	278	363	485	363	344	367	336	299	202
hundreds of acres[c]	1.77	2.31	3.09	2.31	2.19	2.34	2.14	1.91	1.29

Notes:

[a] From Tables 7 and 8 (based on References 1, 2, 3, and 4).

[b] Regional figures may not add up to national totals due to rounding of percentages given in Table 8.

[c] Acreages based on algorithm given in Section 1.

Estimates of wastewater treated by lagooning prior to 1968 were made on the basis of FWPCA estimates[2] for 1968 and consideration of discharge volumes and the state of wastewater treatment technology for the period. The 1954 percentage was thus estimated to be about 30 percent of that for 1968. Regional percentage projections for 1954-1964 lagooning treatment approximate the national percentages, but take into account the amount of lagooning being done in each region as of 1968.

Table 10. Estimated percentages of total wastewater discharged receiving treatment in lagoons in the petroleum refining industry, 1954–1983.

	1954[a]	1959	1964	1968[b]	1971[c]	1973[c]	1975[c]	1977[c]	1983[d]
Delaware and Hudson[e]	9	15	22	29	36	42	49	55	50
Eastern Great Lakes[f]	—	—	—	—	—	—	—	—	—
Ohio River[e]	8	14	21	28	35	41	48	55	50
Western Great Lakes[e]	3	5	7	10	20	30	40	50	45
Upper Mississippi[e]	18	32	46	60	60	67	60	55	55
Lower Mississippi[f]	—	—	—	—	—	—	—	—	—
Missouri[e]	24	42	60	79	80	80	75	70	65
Arkansas[e]	21	37	54	71	73	75	70	70	60
Western Gulf[e]	11	19	27	36	42	48	54	60	50
California[e]	22	38	55	72	73	75	70	70	60
United States	8	14	21	28	36	44	52	60	50

Notes:

[a] 1954 national and regional projections based on FWPC estimates[2] that lagooning was only about 30 percent as prevalent as in 1968; 1959 and 1964 interpolated.

[b] 1968 regional and national data from Reference 4 used as a baseline for 1954–1964 and 1971-1983 projections.

[c] 1971-1977 national projections assume increasing use of lagooning to meet EPA 1977 criterion of "best practicable technology."

[d] 1983 projections assume increasing use of techniques other than lagooning to meet EPA criterion of "best available technology."

[e] Regional percentage distributions approximate the national percentages but take into account regional amount of lagooning as of 1968.

[f] No lagooning data.

The national projections for lagooning from 1971-1983 were based on two assumptions: (1) that through 1977 lagoons would fulfill EPA's "best practicable technology" criterion for secondary treatment of wastewater, and (2) that by 1983 their use will most likely be declining as other secondary treatment techniques are adopted (eg, activated sludge) because of EPA's requirement for use of "best available technology" by that date. These assumptions tend to be confirmed by FWPCA estimates[2] of adoption rates of various secondary treatment techniques (activated sludge, aerated lagoons, oxidation ponds) by petroleum refineries from 1963 through 1977. The regional projections for 1971-1983 approximate the national percentages, but vary to some degree depending upon the 1968 baseline percentages.

Table 11 contains the estimated volume and acreage of petroleum refinery wastewater treatment lagoons for 1954-1983 as developed from the data of Table 7 (total volume discharged) and Table 10 (estimated percentage treated). Again, the acreage figures are derived using the algorithm described in Section 1 and assuming a 6-foot lagoon depth and a 20-day detention time.* Unlike the unlined sedimentation basin acreage estimates, however, the lagoon acreage estimates were multiplied by a factor of 1.5 to allow for the additional volume required for longer filling and emptying times and the much longer detention times.

REGIONAL POLLUTION IMPLICATIONS

Table 9 shows that from 1954 to 1983 the regions with the greatest volume of petroleum refinery wastewater processed in unlined sedimentation basins are the Western Gulf and the Delaware and Hudson regions. As projected, the Western Gulf in 1954 accounted for 30 percent of the national total and the Delaware and Hudson 24 percent, and these regions

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*Lagoon aeration is more prevalent in the petroleum refining industry than in the others studied; hence the assumption of a 6-foot depth for lagoons instead of a 4-foot depth.

Table 11. Volume and acreage of wastewater in lagoons in the petroleum refining industry, 1954–1983.[a]

Region[b]	1954	1959	1964	1968	1971	1973	1975	1977	1983
Delaware and Hudson									
billions of gallons	28	50	77	93	123	149	181	211	216
hundreds of acres	14	26	39	47	63	76	92	108	110
Eastern Great Lakes[c]	—	—	—	—	—	—	—	—	—
Ohio River									
billions of gallons	3	5	6	8	11	13	16	19	20
hundreds of acres	3	3	3	4	6	7	8	10	10
Western Great Lakes									
billions of gallons	4	8	13	16	34	52	72	95	96
hundreds of acres	2	4	7	8	17	27	37	48	49
Upper Mississippi									
billions of gallons	2	4	5	9	10	11	10	10	10
hundreds of acres	1	2	3	5	5	6	5	5	5
Lower Mississippi[c]	—	—	—	—	—	—	—	—	—
Missouri									
billions of gallons	—	—	13	15	16	17	17	16	17
hundreds of acres	—	—	7	8	8	9	9	8	9
Arkansas									
billions of gallons	2	5	8	10	11	11	11	12	11
hundreds of acres	1	3	4	5	6	6	6	6	6
Western Gulf									
billions of gallons	29	53	90	120	149	177	207	239	225
hundreds of acres	15	27	46	61	76	90	105	122	115
California									
billions of gallons	27	52	76	73	79	85	82	85	82
hundreds of acres	14	27	39	37	40	43	42	43	42
United States									
billions of gallons	90	168	277	342	466	593	729	875	821
hundreds of acres	45	86	141	174	238	303	372	446	419

Notes:

[illegible] Tables 7 and 10 (based on References 1, 2, 3, and 4).

[illegible]onal figures may not add up to national totals due to independent rounding.

[illegible] lagooning data.

show fractions of 30 and 26 percent, respectively, for 1983. Total volume treated by unlined sedimentation peaks at 115 billion gallons in 1973 for the Western Gulf region and at 102 billion gallons in 1973 for the Delaware and Hudson region. The third and fourth largest processors by unlined sedimentation in 1973, when the national volume peaks at 367 billion gallons, are the Western Great Lakes and Lower Mississippi regions with 37 billion and 35 billion gallons, respectively.

The Western Gulf and Delaware and Hudson regions also are projected to process the largest volumes of wastewater in lagoons throughout the 1954-1983 period, as shown in Table 11. The respective fractions of water lagooned in 1983 are about 27 percent and 26 percent of the national total for these two regions, with the Western Gulf region ranging from 29 billion gallons in 1954 to 225 billion gallons in 1983. The 29-year total for the Western Gulf region amounts to more than 4,000 billion gallons with the Delaware and Hudson region only slightly less. Also lagooning large quantities of wastewater are the Western Great Lakes and California regions.

The acreage covered by the effluent is the primary indicator of the potential threat to groundwater quality. The areas covered by unlined sedimentation and lagooning (see Tables 9 and 11) were calculated for the petroleum refining industry in a manner similar to that described for the pulp and paper industry except that no credit was given for expected technological advances in lagooning. Increasing use of aeration, for example, would tend to decrease the acreage required for lagoons, decrease detention times for treatment, or both. In addition, the analysis does not take into account regional and seasonal variations in detention times because of climatic effects on BOD reduction.

Although the regional figures do not show concentrations of lagoons, it is perhaps noteworthy that the Delaware and Hudson region, which lagoons a quarter of the nation's refining industry wastewater, is also one of the smallest industrial water use regions in the country. At the projected rate of growth in lagooning, during the 1977 period this region will contain 10,800 acres – about 17 square miles – of lagoons. Assuming that the lagoon seepage rate of 30 inches per year adopted for this study is reasonable, the potential exists for 27,000 acre-feet per year of polluted water to seep underground in this region alone.

NATIONAL POLLUTION IMPLICATIONS

Table 12 shows the volume of and area covered by wastewater in unlined sedimentation basins and lagoons in the petroleum refining industry, at the national level. The total wastewater discharged peaks in 1964, declines for several years due to recirculation of cooling water, then rises to another peak in 1983. The volume of wastewater treated by unlined sedimentation peaks in 1964, while the volume treated by lagooning peaks in 1977. The large increase in secondary treatment that has been assumed causes the volume and area of lagoons to increase substantially from 1964 to 1977, with a proportionate increase in the potential for wastewater to infiltrate into the ground.

Table 12. U.S. petroleum refining industry wastewater volume discharged, volume treated before discharge, and area covered by treatment processes, 1954–1983.

Item	1954	1959	1964	1968	1971	1973	1975	1977	1983
Total wastewater discharged (billions of gallons)	1,130	1,200	1,320	1,220	1,295	1,347	1,401	1,458	1,642
Volume treated in unlined sedimentation basins (billions of gallons)	278	363	502	366	344	367	336	299	202
Area covered by wastewater in unlined sedimentation basins (hundreds of acres)	1.77	2.31	3.20	2.33	2.19	2.34	2.14	1.91	1.29
Volume treated in lagoons (billions of gallons)	90	168	277	342	466	593	729	875	821
Area covered by wastewater in lagoons (hundreds of acres)	45	86	141	174	238	303	372	446	419

Source: Tables 7, 9 and 11 (based on References 1, 2, 3, and 4).

At the projected nationwide rates of growth and assumed seepage rate for lagoons, by 1977 more than 111,000 acre-feet per year of effluent might seep into the ground. It must be emphasized, however, that the projections used for the petroleum refining industry are not forecasts, but serve primarily to demonstrate a methodology for the estimation of potential groundwater impacts. Much closer scrutiny of industry practices and trends would be necessary to verify the assumptions used. An assumption that unlined sedimentation and lagooning volumes will decrease throughout the projection period because of more rapid adoption of separators, activated sludge processes, etc, may be as defensible as the assumptions that were used.

COMPOSITION OF EFFLUENT

Petroleum refining is a very complicated process, involving many steps and subprocesses. Little data are available in the literature as to specific pollutants in the wastewater from these various subprocesses. In a survey by the FWPCA,[2] it was observed that:

> Wastewater surveys from only five refineries had pollutant concentration and wastewater flow data suitable for determination of waste loadings from individual subprocesses. . . . Because of the limited amount of data available, breakdown of waste-loading on a sub-process basis was considered impractical and of doubtful validity.

According to FWPCA, six pollutants commonly found in the effluent from petroleum refineries are of consequence to groundwater quality:

1. Oil
2. Ammonia
3. Suspended solids
4. Phenols
5. Spent caustics (alkaline waters)
6. Sulfides.

According to the EPA,[10] petroleum refinery wastewater also contains several other pollutants, occurring in smaller but unspecified amounts and concentrations:

1. Bromine
2. Carbon monoxide
3. Boric acid
4. Magnesium chloride
5. Ammonium carbonate
6. Ammonium sulfide
7. Cyanide
8. Ammonium thiocyanate
9. Ammonium ferrocyanide.

SECTION 4

PRIMARY METALS INDUSTRIES WASTEWATER

INTRODUCTION

Although a large volume of water is used in the primary metals industries in the United States, only about 25-30 percent of this is used for anything other than cooling purposes.[2,11] Therefore, the major volume is not subjected to treatment practices that threaten groundwater quality. In 1968, for example, 1,430 billion gallons of wastewater underwent primary and/or secondary treatment although 4,696 billion gallons were discharged. The major pollutants of consequence to groundwater are suspended and dissolved solids, iron, ammonia, cyanide, phenol, oil, and the heavy metals—arsenic, cadmium, chromium, lead, and zinc. The latter are especially hazardous to human health.[11]

Sixteen of the 18 industrial water-use regions shown in Figure 1 have at least a small amount of primary metals production. However, as shown in Figure 2, production is concentrated principally around the Great Lakes and on the Eastern Seaboard. The regions with the greatest volumes and acreage of wastewater undergoing unlined sedimentation and lagooning are the Eastern Great Lakes, the Western Great Lakes, and the Ohio River. These three areas are expected to continue to treat the largest volumes of wastewater and to have the greatest acreage in use for wastewater treatment throughout the projection period.

The primary references used in this effort were The Cost of Clean Water,[2] Environmental Steel,[11] Census of Manufactures,[3,4] and University of Maryland Bureau of Business Research steel industry growth forecasts.[1] The Standard Industrial Code entry used in the census

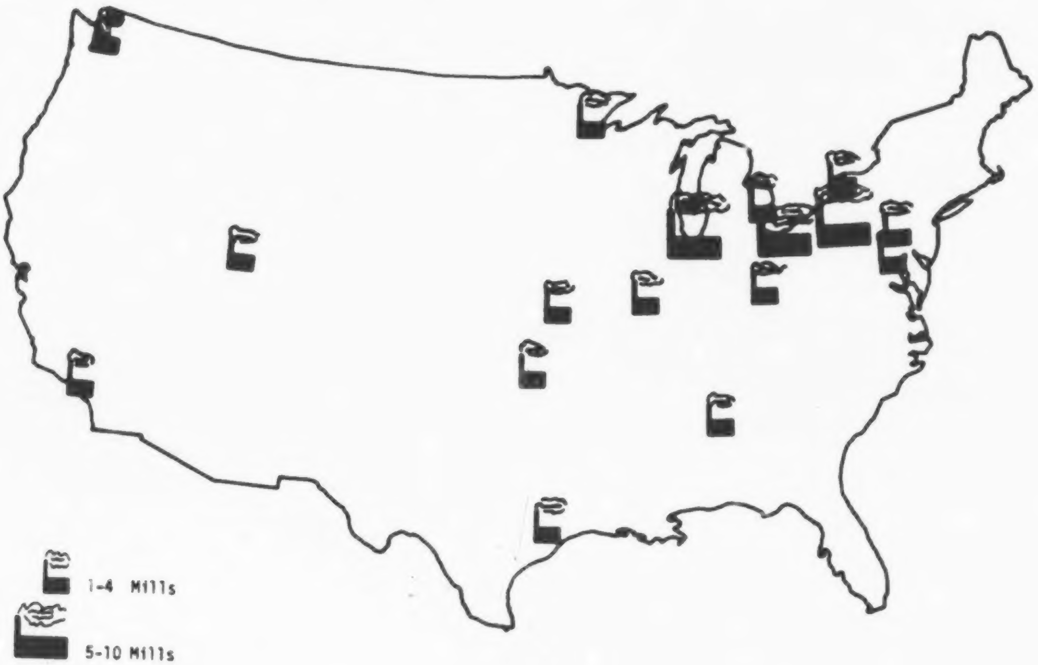

Figure 2. Geographic distribution of steel mills in the United States.

material was Number 33, Primary Metals Industries. The 1967 Census of Manufactures[4] defines "primary metals" as the following:

> . . . establishments engaged in the smelting and refining of ferrous and nonferrous metals from ore, pig, or scrap in the rolling, drawing, and alloying of ferrous and nonferrous metals; in the manufacture of castings, forgings and other basic products of ferrous and nonferrous metals; and in the manufacture of nails, spikes, and insulated wire and cable. This major group also includes the production of coke.

Of the 1,430 billion gallons of wastewater treated in the primary metals industry in 1968, approximately 90 percent, or 1,360 billion gallons, were treated by steel mills and blast furnace operations. Since the Census of Manufactures was a primary data source in this effort and since the emphasis in this study is on demonstrating a methodological approach to estimating the potential groundwater quality implications, rather than on detailed, refined results, the figures for the overall industry of "primary metals" are assumed to be applicable to the specific industries of steel and blast furnaces. As in the paper and petroleum refinery wastewater cases, 1964 and 1968 regional data on wastewater treated and total water discharged were used as a baseline. Regional estimates were made for years prior to 1964 and projections for subsequent years.

APPROACH

Five factors were taken into account in projecting the past and future volume of and acreage covered by steel industry wastewater treatment: industry growth, variations in water usage per unit of production output, changes in the amount of wastewater treated as a percentage of the total amount discharged by the industry, seasonality of production, and technological changes in wastewater treatment practices and methods.

Industry growth estimates for 1968 through 1970 were assumed to be 5 percent per year. The following University of Maryland annual growth estimates of steel industry output were used for the 1971-1983 projections:

Years	Percent/Year
1971-1973	6.03
1974-1975	2.69
1976-1978	1.25
1979-1983	0.67

The second projection factor, water usage per unit of output, was assumed to increase by 10 percent over the industry growth projections for 1977-1983. This increase is based on the introduction of new process technologies that require more water per unit output than present techniques.[2,11] The baseline water discharge figures for 1964 and 1968, the regional estimates based on national totals for 1959 and 1954, and the regional and national projections for 1971-1983 are given in Table 13.

Table 13. Total wastewater discharged by the primary metals industries, 1954–1983, and wastewater treated before discharge, 1964 and 1968 (billions of gallons).

Region[a]	1954[b]	1959[c]	1964[c]		1968[d]		1971[e]	1973[e]	1975[e]	1977[e, f]	1983[e, f]
			discharged	treated	discharged	treated					
New England	37	35	40	1	33	2	39	43	45	52	53
Delaware and Hudson	254	245	278	91	286	86	331	372	392	442	464
Chesapeake Bay	199	190	314	-	324	98	375	422	445	503	525
Eastern Great Lakes	685	659	730	249	820	210	949	1,067	1,125	1,268	1,328
Ohio River	1,307	1,249	1,442	267	1,380	342	1,597	1,795	1,893	2,135	2,234
Tennessee	11	9	24	15	22	14	25	29	31	34	34
Southeast	59	58	44	21	79	23	91	102	108	121	128
Western Great Lakes	733	708	926	308	1,182	544	1,368	1,537	1,620	1,827	1,912
Upper Mississippi	77	74	100	84	120	40	139	155	163	184	191
Missouri	18	16	14	-	20		23	25	27	30	30
Arkansas	22[g]	21[g]	26[g]	-	29	12	34	38	40	44	44
Western Gulf	59	57	139	27	160	15	185	208	220	249	263
Colorado Basin	4	3	7	1	9	<1	10	12	12	13	13
California	11	9	10	9	10	7	12	14	14	15	15
Pacific Northwest	44	43	40	20	55	18	64	72	76	86	91
United States	3,682[h]	3,551[h]	4,312[h]	1,159[h]	4,696[h]	1,431[h]	5,438	6,114	6,447	7,271	7,568

Notes:

[a] Regional figures may not sum to national totals because of independent rounding.

[b] Data on national total from Reference 3; regional distribution assumed to be the same as for 1959

[c] Source for regional data: Reference 3 (except for Arkansas—see Note g).

[d] Source for regional data: Reference 4.

[e] 1971–1983 growth projections from Reference 1.

[f] Ten percent of annual projected regional total added to 1977 and 1983 volume to accomodate new, more water-intensive manufacturing technology.

[g] Arkansas 1954–1964 figures derived from regional percentage for 1968.

[h] U.S. totals for 1954–1968 from Reference 4.

In estimating the quantities of wastewater discharged and treated by the industry from 1954-1983, it was assumed, based on the actual national share receiving treatment in 1964 and 1968 and estimates from References 2 and 11, that only 30 percent of the industry's wastewater would require treatment for other than thermal pollution in order to comply with EPA regulations.* Thus, like the petroleum refining industry, no dramatic increases are anticipated in amount of wastewater treated in order to meet EPA requirements. While some regions showed more than 30 percent treatment in 1964 and 1968,[3,4] this could be attributable to lack of selectivity in treatment or reporting of treatment.

Steel production schedules appear to be constant throughout the calendar year; therefore, basin and lagoon capacities for an even flow of production and a 300-day-per-year work schedule were assumed.

The fifth factor, technological changes in wastewater treatment practices and methods, incorporated various estimates by EPA[2] and the Council on Economic Priorities[11] concerning the prevalence of use of unlined basins and lagoons for primary and secondary wastewater treatment throughout the 1954-1983 projection period. In general, unlined basin primary treatment is viewed as a declining percentage of the total steel industry primary treatment from 1959 to the end of the projection period. Percentage of biological treatment by lagooning is viewed as peaking in the mid-1970s and then declining as more advanced methods are adopted.

VOLUME PROJECTIONS

Unlined Sedimentation Basins

Based on trends indicated for 1964 in Cost of Clean Water,[2] 60 percent of the total wastewater treated was estimated to have received primary treatment in unlined sedimentation basins. For 1959, when the volume of treated wastewater discharged was approximately 50 percent of the 1964 figure, 70 percent was assumed to have received primary treatment in unlined basins. These percentages were also used for 1954, when treated wastewater discharged approximated 50 percent of the 1959 volume.

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*References 2 and 11 estimate that only 25 percent requires treatment; data in References 3 and 4 indicate national averages of 27 percent and 30 percent receiving treatment in 1964 and 1968.

Cost of Clean Water[2] further estimates that in 1968 over 90 percent of the steel industry's treatable water was treated by sedimentation, with more than half of this occurring in unlined basins. It was assumed, therefore, that 60 percent of all sedimentation treatment also occurred in unlined basins in 1968 with the percentage progressively decreasing to 25 percent by 1983, or slightly more than 2 percent per year, in order to account for increasingly stringent EPA requirements and adoption of alternative types of primary treatment techniques. These primary treatment percentage projections are given in Table 14 with projected percentages of total wastewater treated. Regions showing less than 30 percent treatment of total wastewater in 1958 are projected to increase treatment to 30 percent by 1977; for those regions which reported more than 30 percent sedimentation treatment of total wastewater discharged in 1968, the 1968 figures are used for 1970–1983.*

Table 15 contains the projected regional and national volumes and acreages of unlined sedimentation basins as derived from Tables 13 and 14. The volumes are estimated as total wastewater discharged (Table 13) times percentage of total wastewater receiving primary treatment times percentage of primary treatment done in unlined basins (Table 14). The acreage-covered figures of Table 15 assume an average depth for

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*For some regions reporting more than 30 percent treatment, the 1964 and 1968 data appear somewhat suspect: four of the six show higher percentages treated in 1964 than 1968. Overall, the 1968 figures appear more compatible with the assumed treatment requirement of 30 percent.

Table 14. Percentages of total discharged primary metals industries wastewater receiving primary treatment and estimated percentages of primary treatment in unlined sedimentation basins, 1954–1983.

Region	1954[a]	1959[a]	1964	1968	1971	1973	1975	1977	1983
New England									
primary treatment %	1	2	<1	6	12	18	24	30	30
% primary in unlined basins	70	70	60	60	55	50	45	40	25
Delaware and Hudson									
primary treatment %	8	15	33	30	30	30	30	30	30
% primary in unlined basins	70	70	60	60	55	50	45	40	25
Chesapeake Bay									
primary treatment %	7	14	27[b]	30	30	30	30	30	30
% primary in unlined basins	70	70	60	60	55	50	45	40	25
Eastern Great Lakes									
primary treatment %	7	15	34	26	27	28	29	30	30
% primary in unlined basins	70	70	60	60	55	50	45	40	25
Ohio River									
primary treatment %	5	9	12	25	27	28	29	30	30
% primary in unlined basins	70	70	60	60	55	50	45	40	25
Tennessee									
primary treatment %	15	31	63	64	64	64	64	64	64
% primary in unlined basins	70	70	60	60	55	50	45	40	25
Southeast									
primary treatment %	8	16	48	29	30	30	30	30	30
% primary in unlined basins	70	70	60	60	55	50	45	40	25
Western Great Lakes									
primary treatment %	10	20	33	46	46	46	46	46	46
% primary in unlined basins	70	70	60	60	55	50	45	40	25
Upper Mississippi									
primary treatment %	13	26	84	33	33	33	33	33	33
% primary in unlined basins	70	70	60	60	55	50	45	40	25
Missouri									
primary treatment %	7	15	27[b]	30[b]	30	30	30	30	30
% primary in unlined basins	70	70	60	60	55	50	45	40	25
Arkansas									
primary treatment %	8	17	27[b]	41	41	41	41	41	41
% primary in unlined basins	70	70	60	60	55	50	45	40	25
Western Gulf									
primary treatment %	7	14	19	9	14	19	25	30	30
% primary in unlined basins	70	70	60	60	55	50	45	40	25
Colorado Basin									
primary treatment %	3	7	14	<1	7	15	20	30	30
% primary in unlined basins	70	70	60	60	55	50	45	40	25
California									
primary treatment %	20	40	90	70	70	70	70	70	70
% primary in unlined basins	70	70	60	60	55	50	45	40	25
Pacific Northwest									
primary treatment %	10	21	50	33	33	33	33	33	33
% primary in unlined basins	70	70	60	60	55	50	45	40	25
United States									
primary treatment %	7	15	27	30	31[c]	32[c]	33[c]	33[c]	34[c]
% primary in unlined basins	70	70	60	60	55	50	45	40	25

Notes:

[a] Regional percentages of total discharge receiving primary treatment in 1954 and 1959 based on fractions of national total discharge receiving primary treatment in 1954, 1959, 1964, and 1968 (ie, 1959 regional fraction = 1/2[(1964 + 1968)/2]; 1954 regional total = 1/4[(1964 + 1968)/2]).

[b] Not reported; assumed to be same fraction as national total.

[c] Weighted national averages (% primary treatment x discharge volume summed by year for all regions and divided by total national discharge volume).

Table 15. Volume of wastewater (billions of gallons) receiving primary treatment in unlined sedimentation basins in the primary metals industries and acreage covered, 1954–1983.

Region[a]	1954	1959	1964	1968	1971	1973	1975	1977	1983
New England									
billions of gallons	-	<1	<1	1	3	4	5	6	4
hundreds of acres[b]	-	-	-	<0.01	0.02	0.03	0.03	0.04	0.03
Delaware and Hudson									
billions of gallons	14	26	55	52	54	56	53	53	35
hundreds of acres[b]	0.09	0.17	0.35	0.33	0.34	0.36	0.34	0.34	0.22
Chesapeake Bay									
billions of gallons	9	20	56	59	62	64	60	60	40
hundreds of acres[b]	0.06	0.13	0.36	0.38	0.40	0.41	0.38	0.38	0.26
Eastern Great Lakes									
billions of gallons	34	69	149	126	141	150	147	152	100
hundreds of acres[b]	0.22	0.44	0.95	0.80	0.90	0.96	0.94	0.97	0.64
Ohio River									
billions of gallons	46	78	160	206	237	252	247	256	166
hundreds of acres[b]	0.30	0.50	1.02	1.31	1.51	1.61	1.58	1.63	1.06
Tennessee									
billions of gallons	1	2	9	8	9	10	9	9	6
hundreds of acres[b]	<0.01	0.01	0.06	0.05	0.06	0.06	0.06	0.06	0.04
Southeast									
billions of gallons	4	6	13	14	15	16	14	14	10
hundreds of acres[b]	0.03	0.04	0.08	0.09	0.10	0.10	0.09	0.09	0.06
Western Great Lakes									
billions of gallons	51	99	185	326	346	354	335	336	220
hundreds of acres[b]	0.33	0.63	1.18	2.08	2.21	2.26	2.14	2.14	1.40
Upper Mississippi									
billions of gallons	7	13	50	24	25	26	24	24	16
hundreds of acres[b]	0.05	0.08	0.32	0.15	0.16	0.17	0.15	0.15	0.10
Missouri									
billions of gallons	<1	1	2	4	4	4	4	4	2
hundreds of acres[b]	-	<0.01	0.01	0.03	0.03	0.03	0.03	0.03	0.01
Arkansas									
billions of gallons	1	3	4	7	8	8	7	7	5
hundreds of acres[b]	<0.01	0.02	0.03	0.05	0.05	0.05	0.05	0.05	0.03
Western Gulf									
billions of gallons	3	6	16	9	14	20	25	30	20
hundreds of acres[b]	0.02	0.04	0.10	0.06	0.09	0.13	0.16	0.19	0.13
Colorado Basin									
billions of gallons	-	-	<1	-	<1	1	1	2	1
hundreds of acres[b]	-	-	-	-	-	<0.01	<0.01	0.01	<0.01
California									
billions of gallons	1	3	5	4	4	5	5	5	3
hundreds of acres[b]	<0.01	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.02
Pacific Northwest									
billions of gallons	3	6	12	11	12	12	11	11	6
hundreds of acres[b]	0.02	0.04	0.08	0.07	0.08	0.08	0.07	0.07	0.04
United States									
billions of gallons	174	332	717	851	934	982	947	969	634
hundreds of acres[b]	1.12	2.12	4.57	5.43	5.96	6.26	6.04	6.18	4.04

Notes:

[a] Regional figures may not add up to national totals due to rounding.

[b] Acreage based on algorithm given in Section 1.

sedimentation basins of 8 feet and a detention time of one-half day, and are calculated using the algorithm described in Section 1.

Lagoons

Reference 4 served as the primary source of volume estimates for wastewater secondary biological treatment by lagooning. This document indicated that of 1,431 billion gallons of wastewater undergoing treatment in 1968 before discharge in the primary metals industry, 352 billion gallons, or 25 percent, received treatment in lagoons.

A comparison of total wastewater discharged and amount treated before discharge for 1964 and 1968 (see Table 13) shows a relatively small percentage increase—only about 3 percent—for these four years. Based on this observation, the 1964 percentage rate of lagoon BOD treatment of treatable wastewater was assumed to be 80 percent of that of the 1968 rate for each region. This same percentage was assumed for 1959 and 1954 also, although it could easily have been lower. However, the volume of water treated before discharge for 1959 was only half that of 1964, and for 1954 only one-quarter that of 1964, so the estimate, even if high, is probably of little consequence to the overall projection.

Reference 2 estimates that in 1968, 10 percent of the steel industry plants treated their wastewater biologically, with the percentage increasing to 15 percent in 1972 and 20 percent in 1977. These percentages were taken to be roughly equivalent to percentages of total wastewater treated biologically and, based upon the estimate that only 25 to 30 percent of the total wastewater requires treatment, were assumed to be equivalent to 40 percent, 60 percent, and 80 percent biological treatment of treatable wastewater. However, because the 80 percent secondary treatment estimate for 1977 falls short of EPA requirements, 80 percent was assumed to be achieved by 1975, with 100 percent treatment of treatable wastewater occurring by 1977. The resulting biological treatment percentage projections for lagooning are given in Table 16.

Table 16. Estimated percentages of treatable wastewater discharged receiving secondary treatment in lagoons in the primary metals industries, 1954–1983.[a]

Region	1954[b]	1959[b]	1964[b]	1968[c]	1971[d]	1973[d]	1975	1977[e]	1983[e]
New England	20	20	20	25[f]	40	55	70	60	40
Delaware and Hudson	62	62	62	78	78	78	78	60	40
Chesapeake Bay	24	24	24	30	44	57	70	60	40
Eastern Great Lakes	17	17	17	21	38	54	70	60	40
Ohio River	12	12	12	15	34	52	70	60	40
Tennessee	39	39	39	49	56	63	70	60	40
Southeast	10	10	10	13	32	51	70	60	40
Western Great Lakes	17	17	17	21	38	54	70	60	40
Upper Mississippi	58	58	58	73	73	73	73	60	40
Missouri	20	20	20	25[f]	40	55	70	60	40
Arkansas	20	20	20	25[f]	40	55	70	60	40
Western Gulf	20	20	20	25[f]	40	55	70	60	40
Colorado Basin	-	-	-	<1	24	47	70	60	40
California	20	20	20	25[f]	40	55	70	60	40
Pacific Northwest	20	20	20	25[f]	40	55	70	60	40
United States	18[g]	18[g]	19[g]	25	39[g]	51[g]	70	60	40

Notes:

[a] 100% of "treatable" wastewater = 30% of total industry wastewater.

[b] 1954–1964 percentages treated assumed to be 80% of 1968 percentage treated.

[c] 1968 percentages-treated data from Reference 4.

[d] 1971 and 1973 projections are interpolations of 1968 and 1975 projections.

[e] 100% secondary treatment assumed for 1977 and 1983 with noted percentages occurring in unlined lagoons and the balance by other processes.

[f] No regional lagooning data; assumed to be equal to national percentage.

[g] Weighted national averages (% secondary treatment x discharge volume summed by year for all regions and divided by total national treatable discharge volume).

It will be noted, however, that the percentages of Table 16 for lagoon treatment in 1968, 1971, 1973, 1975, 1977, and 1983 do not reflect 40 percent, 60 percent, 80 percent, 100 percent, and 100 percent biological treatment, respectively. This is because of a further assumption that a portion of the industry's biological treatment occurs through processes other than unlined lagoons, particularly as technological advances in treatment occur. Thus, unlined lagooning was assumed to account for 70 percent of all biological treatment by 1975, 60 percent by 1977, and only 40 percent by 1983. Each region was projected to 70 percent lagooning of wastewaters by 1975 on the basis of percentage lagooned in 1968. For six of the regions, the 1968 amount was taken to be 25 percent, the national percentage, because no data were available on them. However, all except one had relatively small water discharges and the assumption of 25 percent BOD treatment, if in error, has relatively little effect on the overall projections.

Table 17 gives the volumes and acreages covered over the 1954-1983 projection period by primary metals industries lagoons. The volumes of wastewater lagooned are computed from Tables 13, 14, and 16. They are the product of total water discharged by region and year (Table 13) times percentages of wastewater receiving primary treatment before discharge (Table 14) times percentages of treatable wastewater discharged receiving secondary treatment in lagoons (Table 16). The acreage-covered calculations of Table 17 are based on the algorithm given in Section 1 and are adjusted for anticipated technological improvements in lagooning techniques for all regions: the 1954-1975 calculations assume average lagoon depths and detention times of 4 feet and 20 days, the 1977 calculations depths and detention times of 5 feet and 18 days, and the 1983 calculations depths and detention times of 6 feet and 15 days. In all cases, the lagoon acreages given are inflated by 50 percent to allow for filling and emptying of lagoons, cleaning and maintenance, and the detention times required for BOD treatment.

REGIONAL POLLUTION IMPLICATIONS

As projected, three of the primary metals industries regions account for about 75 percent of the total wastewater treated and discharged throughout

Table 17. Volume and acreage of wastewater in lagoons in the primary metals industries, 1954–1983.

Region[a]	1954	1959	1964	1968	1971	1973	1975	1977	1983
New England									
billions of gallons	-	-	-	-	2	4	8	9	6
hundreds of acres	-	-	-	-	2	3	6	5	2
Delaware and Hudson									
billions of gallons	13	23	57	67	77	87	92	80	56
hundreds of acres	10	18	44	51	59	67	70	44	21
Chesapeake Bay									
billions of gallons	3	7	23	29	50	72	93	91	63
hundreds of acres	2	5	18	22	38	54	71	50	24
Eastern Great Lakes									
billions of gallons	8	17	42	45	97	156	228	231	159
hundreds of acres	6	13	32	34	74	119	174	127	61
Ohio River									
billions of gallons	8	13	21	52	136	261	384	384	268
hundreds of acres	6	10	16	40	104	200	294	212	103
Tennessee									
billions of gallons	<1	1	6	7	9	12	14	13	9
hundreds of acres	-	1	5	5	7	9	11	7	3
Southeast									
billions of gallons	-	1	2	3	9	16	23	22	9
hundreds of acres	--	1	2	2	7	12	18	12	6
Western Great Lakes									
billions of gallons	12	24	52	114	340	381	522	504	352
hundreds of acres	9	18	40	87	260	292	399	278	135
Upper Mississippi									
billions of gallons	6	11	49	29	30	37	39	36	25
hundreds of acres	5	8	37	22	23	28	30	21	10
Missouri									
billions of gallons	-	-	1	2	3	4	6	5	4
hundreds of acres	-	-	1	2	2	3	5	3	2
Arkansas									
billions of gallons	-	<1	1	3	6	9	11	11	7
hundreds of acres	-	-	1	2	5	7	8	6	3
Western Gulf									
billions of gallons	1	2	5	4	10	22	39	45	32
hundreds of acres	1	2	4	3	8	17	30	25	12
Colorado Basin									
billions of gallons	-	-	-	-	-	1	2	3	2
hundreds of acres	-	-	-	-	-	<1	2	2	1
California									
billions of gallons	-	-	2	2	3	5	7	6	4
hundreds of acres	-	-	2	2	2	4	5	3	2
Pacific Northwest									
billions of gallons	1	2	4	5	8	13	18	17	12
hundreds of acres	1	2	3	4	6	10	14	9	5
United States									
billions of gallons	46	96	221	352	657	998	1,489	1,440	1,029
hundreds of acres	35	73	169	269	503	764	1,139	793	394

Note:

[a] Regional figures may not add up to national totals.

all of the projected years except for 1983, when the ratio changes to 45 percent.

Although second in wastewater discharged, the largest of the three in terms of wastewater receiving primary treatment is the Western Great Lakes region (see Table 15). This region is projected to incur a peak wasteload for unlined sedimentation basin treatment in 1973, with basins covering 226 acres processing 354 billion gallons of wastewater. The next largest, the Ohio River region, peaks in 1977 at 163 acres of basins processing 256 billion gallons of wastewater, while the third largest, the Eastern Great Lakes region, peaks at 97 acres of basins and 152 billion gallons of wastewater in the same year. During their peak years, the fractions of the national total of primary metal industries unlined basins for these three regions are Western Great Lakes 36 percent, Ohio River 26 percent, and Eastern Great Lakes 16 percent. From 1954 to its peak year of 1973, the Western Great Lakes region is projected to have a sevenfold increase in unlined basin acreage, from 33 acres to 226 acres. All the other primary metals industries regions exhibit substantial increases in acreage as well.

A similar situation is projected for wastewater secondary processing in lagoons. During the Western Great Lakes region's peak year of 1975, Table 17 shows 39,900 acres of lagoons. The Ohio River region peaks at 29,400 acres in 1975 and the Eastern Great Lakes region at 17,400 acres in the same year. The balance of the regions show areas totaling 27,200 acres for 1975.

At the infiltration levels for unlined basins and lagoons of 30 inches per year assumed for this study, the Western Great Lakes region has in its peak year a groundwater pollution potential of 565 acre-feet of wastewater seepage from its unlined sedimentation basins and nearly 100,000 acre-feet from its lagoons. In their peak years, the Ohio River region has an infiltration potential of 73,900 acre-feet of wastewater and the

Eastern Great Lakes region 43,700 acre-feet. At the projected volumes and acreages of unlined basin and lagoon wastewater treatment, over the 29-year projection period the Western Great Lakes region, which covers about 2 percent of the continental United States land area, could absorb more than 1 million acre-feet of wastewater through subsurface infiltration.

NATIONAL POLLUTION IMPLICATIONS

Table 18 shows the nationwide volumes of wastewater and unlined basin and lagoon acreages for the primary metals industries over the 1954-1983 projection period. The peak year for volume treated and area covered by wastewater in unlined basins and lagoons is projected to occur in 1975, with primary treatment of 947 billion gallons, secondary treatment of 1,489 billion gallons, and an area coverage of 114,500 acres.

More likely of significance to groundwater pollution than these figures, however, which are so aggregated as to have their greatest value in demonstrating a methodological approach, is the fact that about 75 percent of the total volume and coverage occurs in concentrated areas of only three midwest regions of relatively limited extent. Given the assumed industry growth rates, treatment practices, industry distribution, and absorption rates, over the 29-year projection period these areas are subject to wastewater subsurface infiltration of up to 2.25 million acre-feet with its long-term groundwater pollution implications.

COMPOSITION OF EFFLUENT

Several subprocesses of the primary metals industries generate wastewaters which receive primary and secondary treatment. The major subprocesses and their wastewater pollutants for the iron and steel industry, which account for about 90 percent of the primary metals industries, are identified in Table 19. Table 20 gives average concentrations of most of the pollutants listed in Table 19.

Table 18. U.S. primary metal industries wastewater volume discharged, volume treated before discharge, and area covered by treatment processes, 1954–1983.[a]

Item	1954	1959	1964	1968	1971	1973	1975	1977	1983
Total wastewater discharged (billions of gallons)	3,682	3,551	4,312	4,696	5,438	6,114	6,447	7,271	7,568
Volume treated in unlined sedimentation basins (billions of gallons)	175	332	717	851	934	982	947	969	634
Area covered by wastewater in unlined sedimentation basins (hundreds of acres)	1.12	2.12	4.57	5.43	5.96	6.26	6.04	6.18	4.04
Volume treated in lagoons (billions of gallons)	46	96	221	352	657	998	1,489	1,440	1,029
Area covered by wastewater in lagoons (hundreds of acres)	35	73	169	269	503	764	1,139	793	394

Note:

[a] Data from Tables 13, 15 and 17 (based on References 2, 3, 4, and 11).

Table 19. Wastewater pollutants from iron and steel industry processes.[a]

Process Pollutants	Coking	Iron mfg	Steel mfg	Hot finishing	Cold finishing	Cleaning acids and alkalines	Pickling	Plating
BOD	X	X(s)		X	X			
COD	X(s)	X(s)			X			
Suspended solids		X	X	X	X			
Dissolved solids	X	X	X	X	X	X	X	X
pH	X	X	X	X	X	X	X	X
Ammonia	X	X						
Cyanide	X	X						X
Fluoride	X(s)	X	X					
Oil	X(s)	X(s)	X(s)	X	X			
Phenol	X	X(s)						
Sulfates and chlorides	X(s)	X(s)					X	
Iron		X	X	X	X	X	X	X
Arsenic		X			X			X
Cadmium		X(s)	X					
Chromium	X(s)	X(s)						X
Lead			X					
Zinc			X					X

Notes:

[a] Data from Reference 11.

(s) = secondary importance.

Table 20. Average pollutant concentrations in steel industry sedimentation basin and lagoon effluents (pounds per gallon).[a]

Pollutant	Sedimentation basins	Lagoons
Dissolved and/or suspended solids	6.9×10^{-4}	9.2×10^{-4}
Iron	8.5×10^{-5}	
Ammonia	2.5×10^{-5}	3.3×10^{-5}
Oil		6.0×10^{-5}
Cyanide	3.5×10^{-6}	4.67×10^{-5}
Zinc	3.5×10^{-6}	
Fluoride	3.5×10^{-6}	
Phenol		2.33×10^{-6}
Chromium		5.9×10^{-7}
Arsenic	8.35×10^{-8}	8.35×10^{-8}
Cadmium	1.35×10^{-8}	1.35×10^{-8}
Lead	7.55×10^{-7}	
Pickling sulfates		1.60×10^{-2}

Note:

[a] Data from References 2 and 11.

SECTION 5

THE PHOSPHATE ROCK MINING INDUSTRY

INTRODUCTION

The approach used for the phosphate mining industry departs from that employed for the other three wastewater-producing industries examined. The analysis is more specific, because more detailed data were available, and because it is concerned with a single wastewater treatment practice in one limited area. Slime ponds are the treatment process and the area is the western part of Polk County, Central Florida, where 64 percent of the phosphate rock production of the United States originated in 1967.[13] This analysis was made even more specific by concentrating on the Noralyn mining operation of International Mineral and Chemical Corporation, since Noralyn was considered typical of mining operations in the rest of the county.

The analysis also differs from those of the other three industries in that it deals with a much less complex production process. Phosphate rock is mined by shooting hydraulic guns at the phosphate matrix, thereby breaking it up. Through the use of more water the phosphate is separated from the clay, sand tailings, and other soil components. The waste products from the matrix, coupled with the water used to break it up and to separate the phosphate, form a waste slime which must be settled. The resultant sludge must then be disposed of. Slime ponds of two types—"active" and "inactive"—are used for this purpose. Active ponds receive slimy wastewaters and desedimented water is extracted from them for reuse. The only function of the inactive ponds is the disposal of slime; the wastewater is simply allowed to remain in them, resulting in a buildup of sedimentation. Since the inactive ponds do not dry up, both types of ponds present potential for groundwater pollution.

METHOD OF ANALYSIS

The Noralyn operation comprises approximately 20 percent of Polk County's phosphate production. Noralyn and the other major phosphate rock mining operations in Polk County are shown in Figure 3. The EPA and the U.S. Bureau of Mines, which consider the Noralyn operation typical of the other mining operations in the county, have estimated that Noralyn's production of slimy wastewater and use of acreage for its treatment is about 20 percent of Polk County's phosphate operations. A comparison of the production output and slime treatment practices at Noralyn and in Polk County as a whole is given in Table 21. The production capacity

Table 21. Phosphate rock slime ponds at the Noralyn operation, Bonnie, Polk County, Florida and all Polk County, Florida phosphate plants (1967).

Item	Noralyn operation	Polk County
Phosphate rock production capacity (millions of tons)	6[a] (20% of Polk County)	30.4[a] (64% of United States)
Growth projection (% per year)[b]	5	5
Slime production per year (acre-feet)[c]	16,000	80,000
Depth of ponds (feet)	30-40	30-40
Slime pond wastewater acreage[c]		
Area per pond	400	400
Active ponds	2,000	10,000
Inactive ponds	1,600	8,000
Total ponds	3,600	18,000
Additional pond area per year	200	1,000

Notes:

[a] Reference 13.

[b] Reference 1.

[c] From Reference 14.

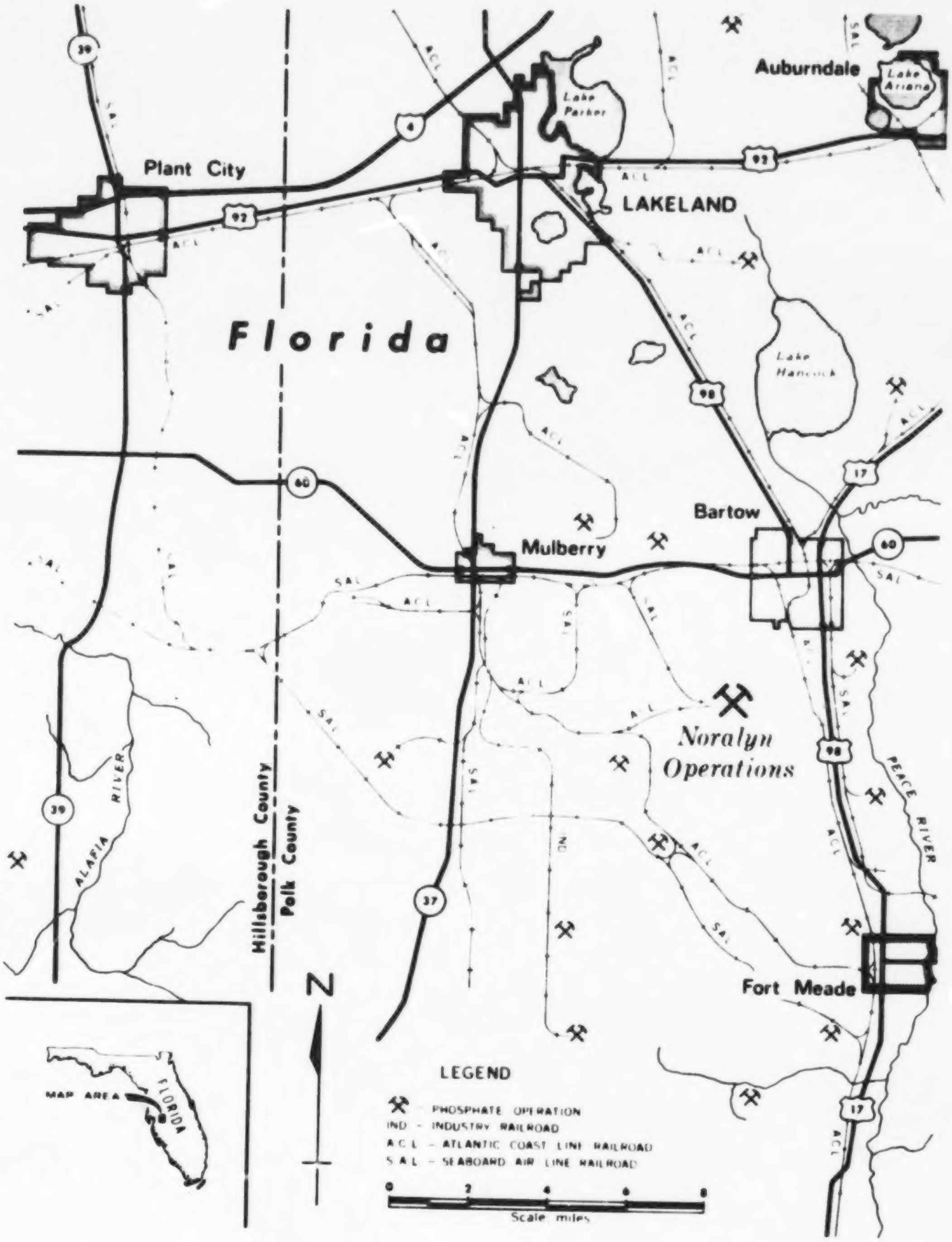

Auburndale
Lake Ariana
Lake Parker
Plant City
LAKELAND
Florida
Lake Hancock
Bartow
Mulberry
Noralyn Operations
Hillsborough County
Polk County
ALAFIA RIVER
PEACE RIVER
Fort Meade
N
MAP AREA
FLORIDA
LEGEND
PHOSPHATE OPERATION
IND - INDUSTRY RAILROAD
A.C.L. - ATLANTIC COAST LINE RAILROAD
S.A.L. - SEABOARD AIR LINE RAILROAD
0
2
4
6
8
Scale miles
39
4
92
98
60
37
17
ACL
SAL
IND

Figure 3. Location map of Noralyn operations.

given in the table is from EPA,[13] while the yearly output of slime for Noralyn is taken from a U.S. Bureau of Mines report.[14] The county-wide slime-production estimates are derived from the Bureau of Mines figures for Noralyn slime production.

The Bureau of Mines estimates that the typical area per slime pond – including both active and inactive ponds – at Noralyn is 400 acres; this figure was assumed to also be applicable to the other operations in Polk County. Total active pond area at Noralyn was estimated by the Bureau of Mines to be 2,000 acres. A map of the Noralyn operation indicates that in 1967 inactive ponds occupied about 80 percent as much area as the active ponds, or 1,600 acres. This ratio was assumed to be typical of the other phosphate mines in Polk County. Thus, for 1967, the base year of the Bureau of Mines report, county-wide acreage of slime ponds was estimated to be 10,000 acres for active ponds and 8,000 acres for inactive ponds.

The Bureau of Mines also estimates that one new 400-acre pond is added at Noralyn every two years, making for an annual increase of 200 acres in ponds at Noralyn and 1,000 acres county-wide. This annual increase in acreage was assumed to be applicable to the years 1966–1970. However, aside from the need to build new ponds to accommodate the then-current level of production as older ponds go out of service, the growth of the industry itself must be considered as well. Reference 1 projects annual growth of the phosphate rock mining industry at about 5 percent per year. Since 1970 is the last year for which production figures were obtained,[12,13] this growth rate is reflected in the 1971–1983 projections of Table 22.

EPA estimates[13] of the production capacities of U.S. phosphate mines were used to derive the 1966–1970 production of Polk County from Bureau of the Census[12] national production figures. The EPA estimates indicate that in 1967 and 1968 Polk County accounted for about 64 percent of the production capacity of the United States, and in 1969 and 1970 about 67 percent. It was assumed that because of normal market competition, actual Polk

Table 22. Phosphate rock production capacity, yearly production, and growth of phosphate rock industry slime ponds in Polk County, Florida and the United States, 1966–1983.

Item	1966	1967	1968	1969	1970	1973[a]	1975[a]	1977[a]	1983[a]
Phosphate rock production capacity (millions of tons)									
United States		47.5	48.6[b]	50.6[b]	50.6[b]	58.9	64.6	71.2	95.4
Polk County		30.4[b]	31.9[b]	33.9[b]	33.9[b]	39.3	43.3	47.7	63.9
Noralyn operation		6.1	6.4	6.8	6.8	7.8	8.7	9.5	12.8
Yearly phosphate production (millions of tons)									
United States	39.0[c]	39.8[c]	41.3[c]	37.7[c]	38.7[c]	44.8	49.4	54.5	73.0
Polk County[d]	25.0	25.5	26.1	25.2	25.9	29.9	33.1	36.5	48.7
Noralyn operation[e]	5.0	5.1	5.2	5.0	5.2	6.0	6.6	7.2	9.8
Pond area added per year nationwide (hundred of acres)	15	16	16	15	15	18	19	21	29
Area covered by phosphate slime ponds (hundreds of acres)[f]									
Polk County	170	180	190	200	210	244	269	297	399
Noralyn operation	34	36	38	40	42	49	54	59	80

Notes:
[a] 1971–1983 production projections based on 5 percent per year growth.[1] [b] From Reference 13. [c] From Reference 12. [d] Based on 64 percent of U.S. production for 1966–1968 and 67 percent for 1969–1983 (from figures noted "b" under production capacity, above). [e] 20 percent of Polk County production. [f] 1971–1983 slime pond area projections based on 39.2 acres of pond per million tons of phosphate production. Figures include normal yearly production increase in pond areas plus industrial output growth factor of 5 percent per annum.

County production was proportional to these percentages, ie, 64 percent and 67 percent of the total U.S. production. The 67 percent production figure was also used to project Polk County's 1971–1983 phosphate production.

The past and projected production of the Noralyn operation was derived as a residual of Polk County's production, based on the EPA and Bureau of Mines estimates that Noralyn represents 20 percent of the county's production. The derived 1967 Noralyn phosphate production of 5.1 million tons and the Bureau of Mines estimated average annual addition of 200 acres of slime ponds to the Noralyn operation yielded a slime pond area factor of 39.2 acres per million tons of phosphate production. This factor was used to calculate the cumulative 1971–1983 slime pond acreages for both the county and Noralyn. It was also used to calculate the annual additional slime pond acreages shown for national production.

The national slime pond area figures, of which only about one-third represent phosphate production outside Polk County, carry with them a further assumption. The slime ponds of the Noralyn operation at Bonnie, Florida are estimated by the Bureau of Mines to be about 40 feet deep and their restraining dams are built to conform to Bureau of Mines specifications. If phosphate slime ponds elsewhere in Florida and other parts of the country conform to the same specifications, based on the Polk County phosphate rock production rate of about 67 percent of the annual national total, total U.S. slime pond coverage would approximate 31,000 acres in 1970 and 60,000 acres by 1983, assuming that mines outside Polk County have the same ratio of active to inactive ponds as the Polk County mines.

COMPOSITION AND CONCENTRATION OF SLIME EFFLUENT

The suspended solids content of wastewater in slime ponds, as well as the mineralogic and chemical composition of these solids, are of potential consequence to groundwater quality. The slime enters the ponds at a solids concentration of 4 to 5 percent and quickly settles to 10 to 15 percent.

Table 23. Approximate mineralogic and chemical composition of phosphate slime solids.[a]

Mineralogic weight composition	Percent
Carbonate fluorapatite	20-25
Quartz	30-35
Montmorillonite	20-25
Attapulgite	5-10
Wavellite	4-6
Feldspar	2-3
Heavy minerals	2-3
Dolomite	1-2
Miscellaneous	0-1

Chemical composition	Typical analyses (%)	Range (%)
P_2O_5	9.06	9-17
SiO_2	45.68	31-46
Fe_2O_3	3.98	3-7
Al_2O_3	8.51	6-18
CaO	14.00	14-23
MgO	1.13	1-2
CO_2	0.80	0-1
F	0.87	0-1
LOI (1,000 C)	10.60	9-16
BPL	19.88	19-37

Note:
[a] From Reference 14.

Further concentration, even after years of settling, never exceeds 25 to 35 percent solids. Therefore, a solids concentration in slime of 10 percent was assumed for active ponds, and 30 percent for inactive ponds. The particular ponds at Noralyn contain an average of about 20 percent solids content in the slime.[14] Their mineralogic and chemical composition is given in Table 23.

The infiltration rate of slime wastewater ponds into underlying groundwater aquifers is assumed to be the same as that described for the other industries' sedimentation basins and lagoons: 30 inches per year. On this basis, Polk County is presently subject to underground infiltration of about 64,000 acre-feet of water per year from its slime ponds. At the projected rate of industry growth, the infiltration in Polk County alone could approximate 100,000 acre-feet per year by 1983. On a national basis, the infiltration may approach 150,000 acre-feet per year by 1983, with about 75 percent of this in Polk County and other parts of Florida, assuming that the industry production distribution does not change greatly.

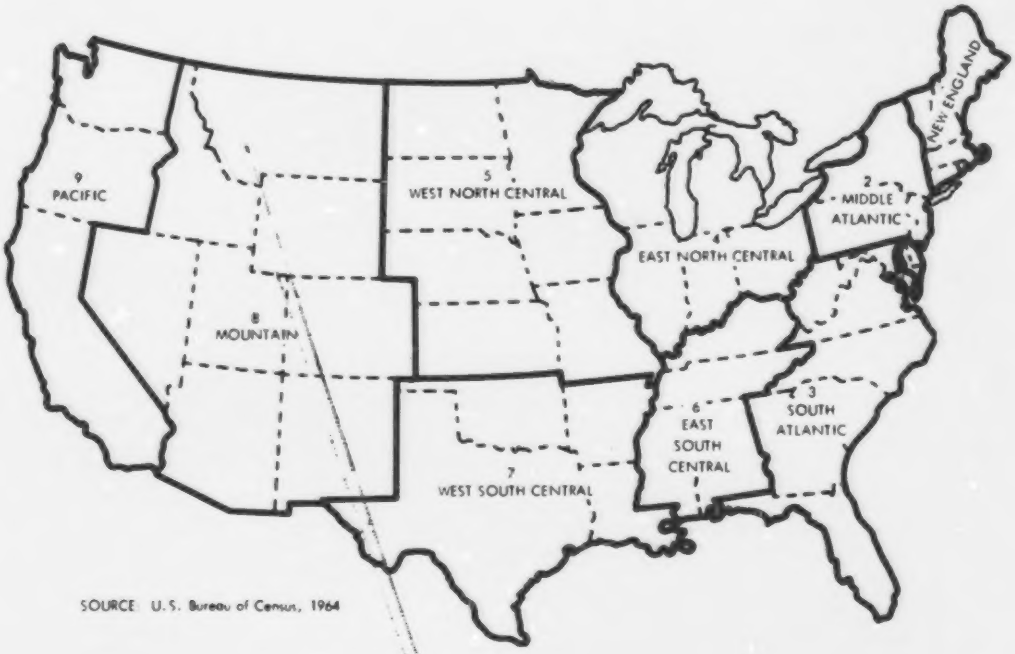
SECTION 6

AGRICULTURAL FERTILIZER CONSUMPTION

INTRODUCTION

National fertilizer consumption increased 1.8 times during the 16-year period from 1954, when 22 million tons were consumed, to 1970, when 40 million tons were consumed. A similar margin of growth is expected between 1970 and 1985, when consumption of 74 million tons is anticipated. Harvested cropland treated with fertilizer shows a less dramatic increase over the same time span, as 123 million acres were fertilized in 1954, 153 million acres in 1970, and 180 million acres are anticipated in 1985. Per-acre application of fertilizer to fertilized harvested cropland is expected to more than double during the 31-year period between 1954, when 0.18 tons were applied per fertilized acre, and 1985, when 0.41 tons per acre are anticipated. Currently, approximately one-quarter of a ton per fertilized acre is the average volume applied in the United States.

The Continental United States (excluding Alaska) is divided by the U.S. Bureau of the Census into the nine fertilizer consumption regions shown in Figure 4. Among these nine regions the largest historical and projected consumers of fertilizer and fertilizers of harvested cropland are the South Atlantic region, the East North Central region, and the West North Central region. The East and West North Central regions are also the largest holders of cropland in corn and wheat, which occupy more fertilized acreage than any other crops in the country. The South Atlantic region, the Pacific region, and the New England region apply the greatest volumes of fertilizer per acre fertilized.


9
PACIFIC
8
MOUNTAIN
5
WEST NORTH CENTRAL
7
WEST SOUTH CENTRAL
4
EAST NORTH CENTRAL
6
EAST
SOUTH
CENTRAL
3
SOUTH
ATLANTIC
2
MIDDLE
ATLANTIC
1
NEW ENGLAND

SOURCE: U.S. Bureau of Census, 1964

Figure 4. Fertilizer-consuming regions of the United States.

The most common constituent of commercial fertilizer consumed in the United States is nitrogen. Also present in large proportions are phosphorus and potash, and in lesser quantities several metals, sulfur, calcium sulfate, boron, and sulfuric acid.

COMPOSITION OF COMMERCIAL FERTILIZERS

Table 24 is taken from a United States Department of Agriculture publication, Commercial Fertilizers, Consumption in the United States.[15] The table lists the 1969 and 1970 U.S. consumption and the 1970 regional consumption of the five most common materials found in commercial fertilizers, and mixtures of these materials. Mixtures, which are made up primarily of nitrogen, phosphate and potash materials, accounted for over one-half of total consumption, while "phosphate materials" and "potash materials" individually comprised approximately 7 percent and 6 percent, respectively. Nitrogen materials comprised approximately 28 percent of total consumption, making it the most widely used individual

Table 24. Types and amounts of fertilizer consumed in the United States, FY1969 and FY1970, and in regions, FY1970 (thousands of tons).[a]

Kind	United States		Regions (FY1970)								
	FY1969	FY1970	New England	Middle Atlantic	South Atlantic	East North Central	West North Central	East South Central	West South Central	Mountain	Pacific
Mixtures[b]	21,234	20,963	308	1,665	5,380	4,366	3,750	2,102	2,053	357	737
Nitrogen materials	10,878	11,898	17	218	1,391	2,094	3,411	880	1,640	677	1,510
Natural organic materials	536	501	17	32	32	42	11	5	10	9	333
Phosphate materials	2,826	2,522	10	78	90	552	654	171	215	315	403
Potash materials	2,140	2,410	8	47	164	1,176	713	128	87	23	56
Secondary and micronutrient materials	1,334	1,296	<1	10	148	5	26	2	1	43	1,058
Total all fertilizers	38,949	39,591	359	2,051	7,205	8,236	8,564	3,287	4,006	1,434	4,098

Notes:

[a] From Reference 14.

[b] Primarily consist of nitrogen, phosphate, and potash materials.

fertilizer material of the five listed in the table. The three primary nutrient materials—nitrogen, phosphates and potash—individually and in mixtures accounted for approximately 95 percent of fertilizer consumption in the country in 1969 and 1970.

The other two fertilizer materials, "natural organic materials" and "secondary micronutrient materials," accounted for 1.4 percent and 3.4 percent, respectively, of national consumption in 1969 and 1970.*

ANALYTICAL APPROACH

Fertilizer Consumption

A straightforward approach was used in estimating fertilizer consumption for the projection period. Historical (1954–1970) data were taken from USDA's Agricultural Statistics.[16] Nonagricultural uses of commercial fertilizer were ignored in the analysis because no data on such consumption could be found. Projected yearly national fertilizer consumption was assumed to be equal to yearly national fertilizer industry production, which was projected using the University of Maryland Bureau of Business and Economic Research industry output forecasts.[1] These forecasts project the following output growth rates for the national fertilizer industry:

Period	Percent/Year
1971–1975	5.11
1976–1980	3.86
1981–1985	3.17

Projected 1971–1985 regional fertilizer consumption estimates were derived by assuming that the regional distribution of total national fertilizer consumption that existed in 1970 would remain unchanged through 1985. The 1970 ratio of fertilized harvested cropland acreage to nonfertilized harvested cropland acreage in each region was assumed to represent the maximum percentage that would benefit from fertilization, and thus remain unchanged through the 1971-1985 projection period. While this assumption may be arguable, it has little effect on the methodology employed. Projected ratios of nonfertilized to fertilized cropland could easily be varied for later years if available data indicated changing trends.

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*"Natural organic materials" used were equal to only about 7 to 8 percent of the manure produced in beef cattle feedlots during the same period (see Section 7).

Fertilized Harvested Cropland Acreage

Data on the number of acres that were treated by fertilizers in 1954-1964 were taken directly from 1959 United States Census of Agriculture[17] and 1964 United States Census of Agriculture.[18] Regional data for 1969 were not available, but the national figure for that year was obtained from Statistical Abstracts, 1972[12] and the regional distribution was assumed to be the same as that for 1964. The regional and national acreage figures for these years are given in Table 25.

Data for fertilized harvested cropland acreage for years subsequent to 1969 were not available, so projections for 1970-1985 were made using a series of three steps. The first step was to obtain the number of acres in total harvested cropland acreage, as shown in Table 26. The figures in Table 26 for 1975 to 1985 result from an assumption that essentially all of the acreage in idle cropland in 1964-1969 will be put to use as harvested cropland by 1975 because of population increases and national policies aimed at increased food production. As an example, the 1975-1985 harvested cropland acreage in Table 26 for the East North Central region is approximated as 64 million acres, based upon the following historical data from the table:

	Acreage	
Cropland	1964	1969
Harvested	56,400,000	54,000,000
Idle	8,420,000	10,400,000
Total	64,820,000	64,400,000

Table 25. Fertilized harvested cropland acreage in the United States by region, 1954–1985 (thousands of acres).

Region	1954[a]	1959[a]	1964[b]	1969[c]	1970[d]	1975[d]	1980[d]	1985[d]
New England	861	995	963	995	976	1,164	1,164	1,164
Middle Atlantic	6,090	5,680	5,300	5,475	5,370	6,406	6,406	6,406
South Atlantic	20,900	18,700	17,200	17,770	17,428	20,788	20,788	20,788
East North Central	31,030	32,300	33,000	34,093	33,437	39,884	39,884	39,884
West North Central	26,400	34,900	44,100	45,560	44,684	53,300	53,300	53,300
East South Central	15,200	12,800	11,600	11,984	11,754	14,020	14,020	14,020
West South Central	11,900	13,300	20,700	21,385	20,974	25,018	25,018	25,018
Mountain	3,360	4,920	6,570	6,788	6,657	7,941	7,941	7,941
Pacific	6,970	9,310	11,100	11,468	11,247	13,416	13,416	13,416
United States	123,000	133,000	151,000	156,000	153,000	182,500	182,500	182,500

Notes:

[a] Regional and national census data.[17]

[b] Regional and national census data.[18]

[c] National census data for total U.S.;[12] regional distribution interpolations based on 1964 distribution.

[d] Based on ratios of fertilized harvested cropland acreage to total harvested cropland acreage.

Table 26. U.S. cropland acreage harvested and cropland acreage idle or in cover crops, 1954–1985 (thousands of acres).[a]

Region	1954[b]	1959[c]	1964[d]	1969[e]	1970[f]	1975[g]	1980[g]	1985[g]
New England								
harvested	3,050	2,380	2,060	1,640	1,610	2,000	2,000	2,000
idle	NA	NA	398	226	NA	-	-	-
Middle Atlantic								
harvested	12,000	11,000	10,000	9,070	9,140	11,000	11,000	11,000
idle	NA	NA	1,850	1,480	NA	-	-	-
South Atlantic								
harvested	23,400	21,400	18,500	20,400	17,000	23,000	23,000	23,000
idle	NA	NA	4,920	4,650	NA	-	-	-
E.N. Central								
harvested	61,200	60,400	56,400	54,000	54,200	64,000	64,000	64,000
idle	NA	NA	8,420	10,400	NA	-	-	-
W.N. Central								
harvested	136,000	131,000	118,000	114,000	116,000	132,000	132,000	132,000
idle	NA	NA	18,000	19,100	NA	-	-	-
E.S. Central								
harvested	20,000	18,100	15,200	15,300	15,300	20,000	20,000	20,000
idle	NA	NA	4,160	4,240	NA	-	-	-
W.S. Central								
harvested	43,900	41,800	37,300	38,700	38,100	45,000	45,000	45,000
idle	NA	NA	7,410	6,320	NA	-	-	-
Mountain		24,800						
harvested	23,700	24,800	22,500	34,600	23,900	26,000	26,000	26,000
idle	NA	NA	4,710	2,788	NA	-	-	-
Pacific								
harvested	14,600	14,300	13,200	13,700	13,600	15,000	15,000	15,000
idle	NA	NA	1,760	1,440	NA	-	-	-
United States								
harvested	337,000	325,000	293,000	287,000	288,000	338,000	338,000	338,000
idle	19,000	33,000	51,600	50,700	NA	-	-	-

Notes:

[a] For 59 principal crops

[b] USDA, 1955[16]

[c] USDA, 1961[16]

NA = Not Available

[e] USDA, 1970[16]

[f] USDA, 1972[16]

[g] 1975–1985 projections assume that all idle cropland acreage becomes harvested acreage by 1975.

The second step in obtaining the fertilized acreage for 1970 through 1985 was to calculate the ratio of fertilized harvested cropland acreage to total harvested cropland acreage, as shown in Table 27, for 1954 through 1969. Although some modifications could be made for 1970–1985 regional

Table 27. Ratios of fertilized harvested cropland acreage to total harvested cropland acreage by region, 1954–1985.

Region	1954[a]	1959[a]	1964[a]	1969[a]	1970[b]	1975[b]	1980[b]	1985[b]
New England	.28	.42	.47	.61	.61	.61	.61	.61
Middle Atlantic	.51	.52	.53	.60	.60	.60	.60	.60
South Atlantic	.89	.87	.93	.87	.87	.87	.87	.87
East North Central	.51	.53	.59	.63	.63	.63	.63	.63
West North Central	.19	.27	.37	.40	.40	.40	.40	.40
East South Central	.76	.71	.76	.78	.78	.78	.78	.78
West South Central	.27	.32	.55	.55	.55	.55	.55	.55
Mountain	.14	.20	.29	.29	.29	.29	.29	.29
Pacific	.48	.65	.84	.84	.84	.84	.84	.84
United States	.36	.41	.52	.54	.54	.54	.54	.54

Notes:

[a] Ratios based on Tables 25 and 26.

[b] Projections assume that 1969 ratio remains unchanged.

trends in cropland fertilization from the 1954–1969 ratios, for this analysis it was assumed that the 1970–1985 ratio of fertilized to unfertilized croplands would remain the same as for 1969.

The final step was to multiply the ratios of Table 27 by the projected number of acres in total harvested cropland for 1970–1985 for each region. This yielded the projected number of acres of fertilized harvested cropland for 1970–1985 given in Table 25.

REGIONAL CONSUMPTION OF FERTILIZERS

Table 28 shows regional fertilizer consumption for 1954–1985. The consumption figures for 1954 through 1970 are census data.[16] The 1975, 1980, and 1985 figures are projections based on fertilizer industry growth rates from Reference 1 and 1970 regional distributions of consumption.

Table 28. Fertilizer consumption in the United States by region, 1954–1985 (thousands of tons).

Region	1954[a]	1959[b]	1964[c]	1969[d]	1970[d]	1975[e]	1980[e]	1985[e]
New England	440	409	458	359	360	460	560	660
Middle Atlantic	1,630	1,500	1,530	1,500	1,570	2,010	2,440	2,860
South Atlantic	6,580	6,620	7,230	7,750	7,780	9,970	12,070	14,190
E.N. Central	4,520	4,780	6,130	8,240	8,760	11,230	13,600	16,000
W.N. Central	2,180	2,870	4,850	8,560	9,120	11,690	14,150	16,630
E.S. Central	2,940	2,960	3,080	3,290	3,360	4,310	5,210	6,130
W.S. Central	1,370	1,530	2,730	4,010	4,170	5,350	6,470	7,600
Mountain	425	588	923	1,430	1,500	1,920	2,330	2,740
Pacific	2,200	3,240	3,990	4,100	4,220	5,410	6,550	7,700
United States	22,300	24,500	30,900	39,200	40,800	52,300	63,300	74,400

Notes:

[a] USDA, 1956[16]

[b] USDA, 1961[16]

[c] USDA, 1966[16]

[d] USDA, 1972[16]

[e] Incorporates fertilizer industry growth projections from Reference 1; regional distribution based on 1970 distribution.

As the table indicates, the South Atlantic region, the East North Central region, and the West North Central region have used, and are expected to use, more tonnage of fertilizer from 1964 to 1985 than any of the other six regions. Of these three, the West North Central region had the highest consumption level in 1970 and is projected to maintain that status through 1985.

As may be noted from Table 25, the East and West North Central regions have the largest shares of fertilized acreage in the country, and the South Atlantic region the fourth largest. The two tables appear to show a fairly consistent, positive relationship between the volume of fertilizer consumed in a given region and the cropland acreage treated with fertilizer. The smallest consumer of fertilizer, the New England region, has the least fertilized acreage, while the second and third smallest consumers, the Mountain region and the Middle Atlantic region, also have the second and third fewest fertilized acres. There is some variation within the remaining four regions, but the relationship between the two variables is generally positive.

Table 29 shows fertilizer application per fertilized cropland acre for 1954-1985. The application figures are derived by dividing past and projected tonnage for each region (Table 28) by the acreage treated (Table 25). Nationwide, per-acre application increased by 50 percent between 1954 and 1970. As projected, a 50 percent increase over 1970 per-acre fertilized application occurs by 1985. The heaviest per-acre usage occurs in the South Atlantic region with 0.68 ton per acre projected for 1985. The second heaviest application—0.57 ton per fertilized acre—is projected for the Pacific and New England regions in the same year. The West South Central region shows the lowest per-acre application—0.30 ton—for 1985.

Table 29. Fertilizer application per fertilized cropland acre, 1954–1985 (tons).

Region	1954	1959	1964	1969	1970	1975	1980	1985
New England	.51	.41	.48	.36	.37	.40	.48	.57
Middle Atlantic	.27	.26	.29	.27	.29	.31	.38	.44
South Atlantic	.31	.35	.42	.44	.45	.48	.58	.68
East North Central	.15	.15	.19	.24	.26	.28	.34	.40
West North Central	.08	.08	.11	.19	.20	.22	.27	.31
East South Central	.19	.23	.27	.28	.29	.31	.37	.44
West South Central	.12	.12	.13	.19	.20	.21	.26	.30
Mountain	.13	.12	.14	.21	.23	.24	.29	.35
Pacific	.32	.35	.36	.36	.38	.40	.49	.57
United States	.18	.18	.20	.25	.27	.29	.35	.41

Source: Tables 25 and 28.

Seasonality of fertilizer use varies widely within and among regions, and may be of considerable significance in estimating the impact of fertilizer use on groundwater quality.[15] The use of a given amount of fertilizer in a single application during a year may have different implications for infiltration, for instance, than smaller applications of the same amount of fertilizer distributed throughout the year. In addition, weather conditions in different seasons in which the fertilizer may be applied might significantly affect the potential pollution from fertilizer use.

Although seasonality of use is recognized here as an important issue, it has not been incorporated into this demonstration analysis: first, because readily available figures (eg, from the USDA Statistical Reporting Service[15]) are for fertilizer purchases by quarters, which may differ drastically from fertilizer use, and second, because the published data were for regions, a level of aggregation much too gross to be of real use since weather, soils, crops, growing cycles, etc, may vary in different parts of a region. Were this demonstration study to be pursued further with more complete and less aggregated data, it might be possible to identify the pollution potential of specific crops because of fertilization and irrigation practices associated with them, particularly if the rainfall, groundwater table level, and soil percolation characteristics of an area were also known.

NATIONAL FERTILIZER CONSUMPTION

Table 30 summarizes Tables 25 through 29 and indicates national historical and projected patterns of consumption and fertilizer application. As the table indicates, from 1954 to 1970, fertilizer consumption increased by 1.8 times. From 1970 to 1985 the same total increase of 1.8 times is expected, although a declining rate of yearly growth is anticipated.

The change in harvested cropland acreage has been much different from that of fertilizer consumption, in that the former shows a steady decline from 1954–1969[16]. By 1970, however, an increase of one million acres over the 1969 figure is evident. Based on the assumption that from 1975 to 1985 all available cropland will have become harvested cropland, 338 million acres are projected to fall within this category during those 10 years. This represents an acreage similar to that of 1954.

Unlike the decline in total harvested cropland, the historical data presented in Table 30 on fertilized harvested cropland exhibit a steady increase from 1954 to 1969.* The ratio of fertilized to total harvested cropland also increased steadily from 1954 to 1969, but because of the assumption that the ratio had stabilized by 1969-1970 no increase is projected beyond these years.

Table 30 shows an historical increase in per-acre application of fertilizer to fertilized cropland such that in 1970 nearly 50 percent more fertilizer was applied per acre than in 1954. Since the number of acres treated by fertilizer is expected to stabilize by 1975, and yet the consumption of fertilizer is expected to continue to increase, per-acre application is also expected to continue to increase. Table 30 projects a steady increase in per-acre application from 1970 to 1985 to approximately two-fifths of a ton per fertilized acre in 1985. This is approximately one and one-half times the quantity used per acre in 1970, and more than double the amount applied per acre in 1954.

applied per acre in 1954.

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*A slight drop is shown from 1969 to 1970 because the 1970 regional estimates were based on USDA data, rather than projections, of total harvested cropland (see Table 25). When these data were combined with projections of the 1970-1985 constant ratio of fertilized to total harvested cropland acreage (see Table 26), the result was a slight regional decline which was reflected in the national total.

Table 30. U.S. consumption of fertilizer, total harvested cropland acreage, fertilized harvested cropland acreage, and intensity of fertilizer application, 1954–1985.

	1954	1959	1964	1969	1970	1975	1980	1985
Fertilizer consumption (thousands of tons)	22, 300	24, 500	30, 900	39, 200	40, 800	52, 300	63, 300	74, 400
Total harvested cropland acreage (thousands)	337, 000	325, 000	293, 000	287, 000	288, 000	338, 000	338, 000	338, 000
Fertilized harvested cropland acreage (thousands)	123, 000	133, 000	151, 000	156, 000	153, 000	182, 500	182, 500	182, 500
Ratio of fertilized harvested acreage to total harvested acreage	.36	.41	.52	.54	.54	.54	.54	.54
Fertilizer application (tons/acre)	.18	.18	.20	.25	.27	.29	.35	.41

SECTION 7

BEEF CATTLE FEEDLOT INDUSTRY

INTRODUCTION

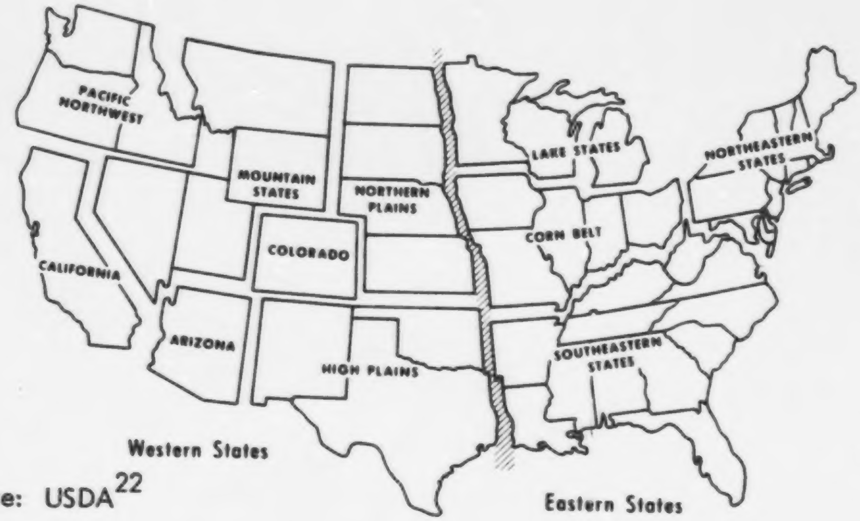
The USDA estimates that approximately 1.39 billion tons of cattle wastes were generated in the nation in 1969.[19] Of this total only about 5 percent was deposited in feedlots, but the environmental threat of wastes concentrated on feedlots is disproportionately large relative to total cattle waste. The Congressional Research Service states, in reference to the environmental threat from cattle wastes, that the major " . . . concern is not with the droppings from grazing animals in pasture lands, but with feedlot production."[20] The brief analysis performed in this study, using estimates of cattle feedlot marketings and population from 1962 through 1983, yields projections of the amount of waste generated in cattle feedlots and acreage devoted to feedlots. The waste and acreage projections for 1983 are more than 30 percent greater than the 1969 levels. Most wastes deposited by beef cattle in feedlots are eventually removed. These wastes may be spread on cropland or pastures, or may be temporarily stacked in or near the feedlot, then spread or bagged to be sold. However, the wastes are generally not prevented from remaining in contact with the ground in the feedlot for at least a brief period.

Particularly when the feedlot is covered, a "pack" of manure forms which becomes essentially impermeable. When the pack is allowed to dry and crack, or if the manure is scraped off down to the surface of the soil, direct infiltration through the area of the feedlot becomes important as a potential source of groundwater pollution.

Rainfall and process water from feedlots (that used for manure flushing or washing) may be caught and treated in holding basins, ponds, or lagoons. When these facilities are in place, infiltration of pollutants into the ground is the major potential threat to groundwater. When feedlots are not adequately equipped with such facilities, and particularly when they are not properly protected by diversion structures to prevent surface drainage from passing through the feedlot, runoff waters will carry wastes either to a low point in the surrounding terrain or to surface streams, or both. The potential contamination of groundwater is then related to the wasteloading and the location of wastewaters, from which contaminants may infiltrate into groundwater.

EPA's regulations proposed in September 1973 specify the best practicable technology currently available, and thus required by 1977, as that which will prevent discharge of pollutants to navigable waters except when rainfall exceeds a 10-year 24-hour event as established by the U.S. Weather Bureau. Effluent limitations representing the best available technology economically achievable, required by 1983, are to prevent discharge of pollutants to navigable waters except when rainfall exceeds a 25-year 24-hour event. Currently, however, " . . . . Waste production by our domestic animals is equivalent to that of a human population of 1.9 billion. Sewage treatment facilities for this livestock are infinitesimal . . . ."[20] This statement is supported by Reference 21, which indicates that only 9 of 46 beef-producing States had regulations directly dealing with feedlot construction or operation in 1972.

For statistical purposes, the United States is divided into eleven beef cattle feedlot production regions (Figure 5), of which the Corn Belt and the Northern Plains are the largest producers. From 1962 to 1972, and projected through 1983, each of these two regions had more beef animals in feedlots, generated greater amounts of beef cattle waste, and had more acreage devoted to feedlots than any other regions of the country.


PACIFIC NORTHWEST
MOUNTAIN STATES
NORTHERN PLAINS
LAKE STATES
NORTHEASTERN STATES
CALIFORNIA
COLORADO
CORN BELT
ARIZONA
HIGH PLAINS
SOUTHEASTERN STATES
Western States
Eastern States

Source: USDA[22]

Figure 5. Cattle feeding regions.

The greatest concentration of cattle on feedlots, and thus the greatest density in waste deposits per acre, occurs in two other regions, California and Arizona.

Table 31 lists the constituents present in beef cattle wastes which may affect groundwater quality. Nitrogen comprises 3.1 to 9.8 percent of total solids, potassium 1.7 to 3.8 percent, and phosphorus 0.3 to 1.7 percent, with other constituents occurring in lesser amounts.

The only reliable data source for the beef cattle industry appears to be the Federal government, which did not record the capacity of feedlot operations until 1962. Thus, the time span of this analysis covers 1962 to 1983, as 1962 is the earliest date for which a usable record of feedlot activity is available.[22] The primary references consulted were the Environmental Protection Agency[24] and the United States Department of Agriculture.[16,23,24] The University of Maryland's Bureau of Business and Economic Research[1] meat industry forecasts were used as the basis for projecting growth in cattle feedlot operations.

Table 31. Cattle waste characteristics in terms of 1000 pounds live weight.

Waste constituents	Beef cattle		
	a	b	c
BOD_5 (lbs/day)	1.7	-	1.02
BOD_5 (lbs/day of volatile solids)	0.45	0.252	0.28 - 0.32
Reaction rate constant ($\log_{10}$)	0.14	-	-
BOD_5/COD (%)	38	-	31 - 40
Nitrogen (total Kjeldahl)			
(% TS)	6.2	9.8	3.1
(lbs/day)	0.30	-	-
Phosphorus (% TS)	1.7	-	1.35
Potassium (% TS)	2.27	-	3.0
Calcium (% TS)	1.16	-	0.8
Magnesium (% TS)	0.47	-	0.65
Zinc (% TS)	0.01	-	-
Copper (% TS)	-	-	0.0005[d]
Iron (% TS)	0.08	-	0.03
Manganese (% TS)	0.01	-	-
Sodium (% TS)	0.09	-	-

Notes:

[a] Values obtained by EPA[23]

[b] Average suggested values by Taiganides (1971)[23]

[c] Calculations based on tabulated values by Loehr (1968)[23]

[d] For dairy cattle;[23] no value given for beef cattle.

APPROACH

Assumptions

Projecting the growth of the beef cattle industry and its attendant waste deposits required assumptions on the size range of feedlot cattle, size trends, seasonality of industry production, and projected regional distribution of the industry. While these factors could be varied by time and region (or some smaller geographic area) in a more detailed study of this type, for this demonstration analysis they were treated uniformly for all regions and periods.

The weight range of beef cattle on feedlots in the Amarillo, Texas area was taken to be representative of feedlots in the rest of the country. Cattle enter Amarillo feedlots at 550 to 650 pounds and leave weighing 1,000 to 1,110 pounds.[25] This average weight-range per head is treated as unchanging throughout the 1962-1983 analysis period.

Like the other industries studied, facility requirements for a given annual output—in this case feedlot area required—are a function of seasonal production schedules. Information from Agricultural Statistics, 1972[16] and Cattle Feeding in the United States[22] on cattle and calves on feed at the beginning of each quarter indicates that production rates are substantially the same for most regions throughout the year.

In projecting regional cattle feedlot production for 1972-1983 the distribution was assumed to be the same as for 1971, the latest year for which data were available.

Method of Analysis

Data for the number of animals marketed from beef cattle feedlots for the years 1962 through 1968 were taken directly from USDA, Cattle Feeding in the United States.[22] Data for 1971 were taken from EPA's National Animal Feedlot Wastes Research Program[24] and USDA's Agricultural Statistics, 1972.[16] Beef cattle industry growth projections for 1973 through 1983 were based upon projections by the University of Maryland's Bureau of Business and Economic Research.[1] These were:

Period	Percent/Year
1971-1973	2.61
1974-1975	3.02
1976-1978	2.67
1980-1983	2.38

The amount of waste deposited on feedlots was estimated by multiplying the number of cattle marketed from feedlots by an average figure for waste produced per animal during its feedlot residence.

A variety of estimates[23,26,27,28] were obtained on the volume of manure generated by feedlot cattle. These ranged from 4.5 tons per year per 1000 pounds of live steer weight to 11.7 tons per year per 1000 pounds of live steer weight; an average value of 8.1 tons per year per 1000 pounds of live steer weight was used. Since cattle enter feedlots at about 600 pounds, and leave at about 1100 pounds, 850 pounds was taken as a typical weight of feedlot cattle during feedlot residence. Thus, a figure of 6.9 tons of manure per year per animal was used in the calculations. Since feedlot residence is about 5 months,[25] the 6.9 tons per year figure was multiplied by 5/12 to obtain an estimate of 2.88 tons of manure deposited per animal during its feedlot residence.

Table 32 shows the number of fed cattle marketed by region and by year for the period 1962-1983. Multiplying the number of animals processed through feedlots by 2.88 tons per animal during feedlot residence yields tons of cattle waste deposited in feedlots by region for the years covered by the projection period. These figures are shown in Table 33.

Using as typical a 5-month feedlot residency of the cattle marketed, and since feedlot activity appears to be fairly constant through the year, the average population in feedlots can be approximated by multiplying cattle marketed (Table 32) by 5/12. The resulting figures are given in Table 34.

Table 32. Number of fed cattle marketed in the United States, by region, 1962–1983 (thousands).

Region	1962[a]	1964[a]	1968[a]	1971[b]	1973[c]	1975[c]	1977[c]	1979[c]	1981[c]	1983[c]
Northeastern States	142	123	139	126	133	141	148	156	164	171
Lake States	985	1,128	1,350	1,361	1,433	1,521	1,603	1,685	1,766	1,851
Corn Belt	5,225	6,037	7,279	6,643	6,994	7,423	7,825	8,225	8,621	9,036
Southeastern States	325[d]	508	492	376[e]	396	420	443	466	488	511
Northern Plains	3,183	4,239	5,562	6,385	6,723	7,135	7,521	7,905	8,286	8,685
High Plains	1,071	1,407	2,705	4,580	4,822	5,118	5,395	5,671	5,944	6,230
Mountain States	314	398	386	235	247	263	277	291	305	320
Colorado	815	951	1,431	2,151	2,265	2,404	2,534	2,671	2,799	2,934
Arizona	568	590	703	901	949	1,007	1,061	1,116	1,169	1,226
Pacific Northwest	627	692	925	950	1,000	1,062	1,119	1,176	1,233	1,292
California	1,844	2,061	2,068	1,990	2,095	2,224	2,344	2,464	2,583	2,706
Total	14,959[f]	18,144	23,040	25,698	27,057	28,716	30,270	31,818	33,350	34,957

Notes:

[a] From Reference 22.

[b] From Reference 24.

[c] Based upon industry growth projections[1] and 1971 regional distributions.

[d] Alabama and Georgia data only.

[e] Extrapolation of Alabama and Georgia first-quarter data from Reference 16 (extrapolated total SE States production = 1.38 million head).

[f] Data listed as given in Reference 22; column sums to slightly more than total shown.

Table 33. Amount of beef cattle manure deposited on feedlots in the United States by region, 1962–1983 (thousands of of tons).[a]

Region	1962	1964	1968	1971	1973	1975	1977	1979	1981	1983
Northeastern States	409	354	400	363	383	406	426	449	472	492
Lake States	2,837	3,249	3,888	3,920	4,127	4,380	4,617	4,853	5,086	5,331
Corn Belt	15,048	17,387	20,964	19,132	20,143	21,378	22,536	23,688	24,828	26,024
Southeastern States	936	1,463	1,417	1,083	1,140	1,210	1,276	1,342	1,405	1,472
Northern Plains	9,167	12,208	16,019	18,389	19,362	20,549	21,660	22,766	23,864	25,013
High Plains	3,084	4,052	7,790	13,109	13,887	14,740	15,538	16,332	17,119	17,942
Mountain States	904	1,146	1,112	677	711	757	798	838	878	922
Colorado	2,347	2,739	4,121	6,195	6,523	6,924	7,298	7,692	8,061	8,450
Arizona	1,636	1,699	2,025	2,595	2,733	2,900	3,056	3,214	3,367	3,531
Pacific Northwest	1,806	1,993	2,664	2,736	2,880	3,059	3,223	3,387	3,551	3,721
California	5,311	5,936	5,956	5,731	6,034	6,405	6,750	7,096	7,439	7,793
Total	43,082[b]	52,255	66,355	74,010	77,924	82,702	87,178	91,636	96,048	100,676

Notes:

[a] Based on Table 32 and manure deposits of 2.88 tons/5 months/head.

[b] Based on USDA total number of beef cattle in feedlots;[22] note that this column does not sum to total shown because of USDA data from Table 32.

Table 34. Average number of beef cattle on feedlots in the United States, by region, 1962–1983 (thousands).

Region	1962	1964	1968	1971	1973	1975	1977	1979	1981	1983
Northeastern States	59	51	58	52	55	59	62	65	68	71
Lake States	410	470	562	567	597	634	668	702	736	771
Corn Belt	2,177	2,515	3,032	2,767	2,914	3,096	3,260	3,427	3,592	3,764
Southeastern States	135	212	205	157	165	175	185	194	203	213
Northern Plains	1,326	1,766	2,317	2,660	2,801	2,972	3,133	3,293	3,452	3,618
High Plains	446	586	1,127	1,908	2,009	2,132	2,248	2,363	2,476	2,595
Mountain States	131	166	161	98	103	110	115	121	127	133
Colorado	340	396	596	896	944	1,002	1,056	1,113	1,166	1,222
Arizona	237	246	293	375	395	420	442	465	487	511
Pacific Northwest	261	288	385	396	417	442	466	490	514	538
California	768	859	862	829	873	927	977	1,027	1,076	1,127
Total	6,232	7,559	9,598	10,706	11,272	11,963	12,610	13,255	13,894	14,563

The area occupied by beef cattle feedlots was calculated by multiplying the number of cattle on lots in each region by an estimate of the square footage normally allotted per head. Four estimates on square footage of feedlot area per head were obtained. These were:

- Arizona: 130–150 sq ft per head*
- Corn Belt: 200 sq ft per head†
- Northern Plains: 200 sq ft per head†
- California:
  - N. California: 50–212 sq ft per head[29]
  - S. California: 130–150 sq ft per head*
  - California Mean: 135 sq ft per head.

These four regions represent over one-half of the beef cattle feedlot production in the United States for 1971, and are projected to represent the same share in 1983.

No data were found on the regions which comprise the remainder of the beef cattle feedlot industry in the United States. One source** suggested a national average area per feedlot head of 200 square feet. This figure was used to calculate the feedlot areas of the remaining regions for which estimates were not available.

The areas of feedlots for 1962–1983 are computed in Table 35 from the feedlot area per head estimates and the beef cattle feedlot population figures of Table 34.

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*Personal communication with Donald Addis, feedlot farm advisor, University of California, Riverside Agricultural Extension, September 1973.

†Personal communication with Professor Garrett, University of California at Davis, Agricultural Department, September 1973.

**Dr. James Elam, feedlot management and cattle nutrition consultant, Santa Ynez, California, September 1973.

Table 35. Area of beef cattle feedlots in the United States, by region, 1962–1983 (thousands of acres).

Region	1962	1964	1968	1971	1973	1975	1977	1979	1981	1983
Northeastern States[a]	0.27	0.23	0.27	0.24	0.25	0.27	0.28	0.30	0.31	0.33
Lake States[a]	1.88	2.16	2.58	2.60	2.74	2.91	3.06	3.22	3.38	3.54
Corn Belt[a]	9.99	11.54	13.91	12.69	13.37	14.20	14.95	15.72	16.48	17.27
Southeastern States[a]	0.62	0.97	0.94	0.72	0.76	0.80	0.85	0.89	0.93	0.98
Northern Plains[a]	6.08	8.10	10.63	12.20	12.85	13.63	14.37	15.11	15.83	16.60
High Plains[a]	2.05	2.69	5.17	8.75	9.22	9.78	10.31	10.84	11.36	11.90
Mountain States[a]	0.60	0.76	0.74	0.45	0.47	0.50	0.53	0.56	0.58	0.61
Colorado[a]	1.56	1.82	2.73	4.11	4.33	4.60	4.84	5.11	5.35	5.61
Arizona[b]	0.76	0.79	0.94	1.21	1.27	1.35	1.42	1.50	1.57	1.64
Pacific Northwest[a]	1.20	1.32	1.77	1.82	1.91	2.03	2.14	2.25	2.36	2.47
California[c]	2.38	2.66	2.67	2.57	2.70	2.87	3.02	3.18	3.33	3.49
Total	27.39	33.04	42.35	47.36	49.87	52.94	55.77	58.68	61.48	64.44

Notes:

[a] Estimated area per head 200 sq ft = 218 head/acre.

[b] Estimated area per head 140 sq ft = 311 head/acre.

[c] Estimated area per head 135 sq ft = 323 head/acre.

SUMMARY OF BEEF CATTLE FEEDLOT ACTIVITY

Table 33 shows that the two leading feedlot regions of the country, the Corn Belt and the Northern Plains, generated 15 million tons and 9 million tons of manure deposits, respectively, in 1962. By 1983, the former is expected to be generating 26 million tons per year, and the latter 25 million tons per year. Over the entire projection period, the national total increases from about 43 million tons per year to 101 million tons per year.

Table 35 shows that in 1971, and projected through 1983, the four areas with the greatest amount of land covered by beef cattle feedlot wastes are the Corn Belt, the Northern Plains, the High Plains, and Colorado. For the entire 21-year period, the two highest ranking regions are, again, the Corn Belt, with a feedlot area of 10,000 acres in 1962 and a projection of 17,000 in 1983, and the Northern Plains, with 6,000 acres in 1962 and a projection of nearly 17,000 acres in 1983.

Based on waste deposits of 6.9 tons per year per head and the per-head area allotment estimates given earlier, the feedlot acreages of Table 35 are subject to about 1,500 tons of waste deposits per year per acre, with the exception of the Arizona and California regions. Assuming that feedlots are used to full capacity, Arizona region feedlots receive annual deposits of about 2,150 tons per acre and California region feedlots slightly more, about 2,200 tons per acre.

Table 36 summarizes Tables 32 through 35. As may be noted, about 15 million head of cattle went through feedlots in the United States in 1962. The number had increased by more than 10 million by 1971, and is projected to increase to approximately 2 1/3 times the 1962 production by 1983. The amount of waste generated follows the same pattern of change over this 21-year period. In 1962, 43 million tons of beef cattle waste material were deposited in feedlots, increasing to 74 million tons by 1971. Again, the 1962 figure is expected to more than double by 1983, when 101

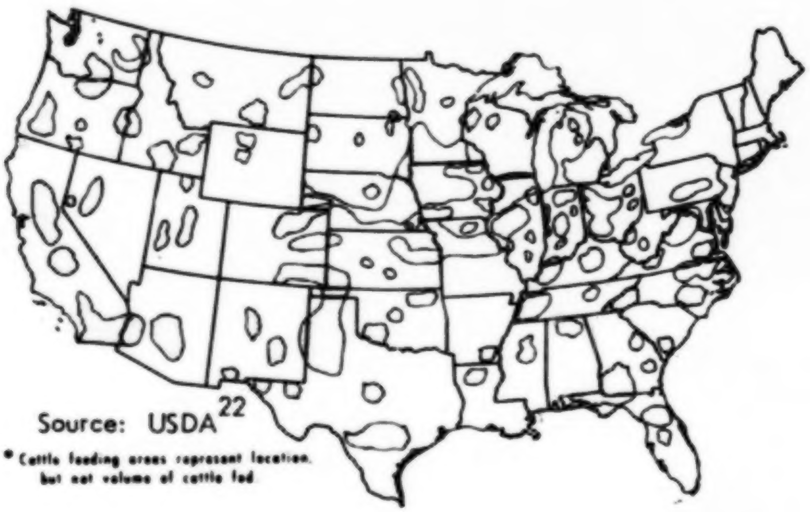
Table 36. Number of beef cattle, feedlot populations, amount of waste deposits, and area covered by feedlots in the United States, 1962–1983.

	1962	1964	1968	1971	1973	1975	1977	1979	1981	1983
Cattle marketed from feedlots (thousands)	14,959	18,144	23,040	25,698	27,057	28,716	30,270	31,818	33,350	34,957
Average feedlot population (thousands)	6,232	7,559	9,598	10,706	11,272	11,963	12,610	13,255	13,894	14,563
Waste deposits in feedlots (thousands of tons)	43,082	52,255	66,355	74,010	77,924	82,702	87,178	91,636	96,048	100,676
Area of feedlot deposits (thousands of acres)	27.39	33.04	42.35	47.36	49.87	52.94	55.77	58.68	61.48	64.44

million tons are projected. To view the problem in a slightly different context, those feedlots in existence in 1962 will have accumulated over 31,000 tons of waste per acre by 1983.

The above amounts of waste deposits occupy increasing acreage in feedlot operations in the country over the 1962 to 1983 period. Assuming a national average feedlot animal population of 200 square feet per animal, about 27,000 acres were utilized as feedlots in 1962, 47,000 acres in 1971, and 64,000 acres, or 100 square miles, are projected for 1983.

No attempt was made to assess the pollution potential of cattle feedlots in this demonstration study, but a few generalized observations can be made. The two leading feedlot regions, the Corn Belt region and the Northern Plains region, form a rough grain farming and livestock-growing continuum that extends easterly from the south central part of the Northern Plains region, traverses the Missouri and Mississippi Rivers, and terminates in the western part of Ohio (see Figure 6). Rainfall in the two regions ranges from moderate in the west to abundant in the east.



Source: USDA[22]

* Cattle feeding areas represent location, but not volume of cattle fed

Figure 6. Cattle feeding areas.*

The industry output growth projections, feedlot acreage, and per head per year waste deposit estimates used indicate that over the 21-year projection period, more than 0.8 billion tons of cattle feedlot wastes will have been deposited in these two regions. This represents about one-half the total U.S. cattle feedlot waste deposits during the projection period in an area that is less than 15 percent of the total U.S. area; ie, a regional concentration of about six times that of the rest of the country.

While important, the three factors of rainfall, waste deposit tonnages, and areal extent do not wholly determine the groundwater pollution threat, which depends also on many other factors such as waste deposit control and disposal practices (if any), concentrations of feedlot activities within the regions, local topography and water table characteristics, soil porosity and sorption characteristics, and groundwater withdrawal rates.

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